ABOUT THIS BOOK

Most of us know too little of the way our bodies work, and are liable in that state of comparative ignorance to become the victims of groundless anxieties about ourselves. In this compact and authoritative survey Mr Kenneth Walker sets forth in plain language the most up-to-date knowledge on the functioning of the human body, and reminds us too how profoundly the mind influences the working of the body.

Starting from the cell, the basis of human as of all life, he describes the nature and work of the digestive, circulatory, excretory, locomotor and nervous systems: the part that food plays in our lives; how we breathe: the functions of the special senses and the physiology of sensation; the chemistry of the body and the glandular system; and the processes of reproduction. A number of sketches in the text illustrate special points.

This book, specially written for the Pelican series, is now in its second large printing.

PELICAN BOOKS

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HUMAN PHYSIOLOGY

BY KENNETH WALKER

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PREFACE

It is generally recognised that the man equipped with a small amount of knowledge is often in a more dangerous position than one who has no knowledge at all. His information may be just sufficient to allow him to reach erroneous conclusions. In no department of learning is this more likely to be the case than in physiology and in medicine. Most doctors can recall the day when, as medical students, they reached the conclusion that they were suffering from the symptoms of some grievous and dangerous disease which they happened to be studying. By the aid of additional knowledge these fears were readily dispelled. It was with the full knowledge of this danger that the author undertook the task of writing this elementary work on physiology. This danger was increased because, in order to demonstrate the normal function of an organ, he has often had to describe its abnormal functioning in disease. At the same time, he has taken care to emphasise the fact that the mind has a profound influence on the working of the body, and that anxiety is one of the body's worst enemies. The old adage, 'Mens sana in corpore sano', is usually interpreted as meaning that to have a healthy mind one must also have a healthy body. It is equally true that a healthy mind is a necessity to a healthy body. This is the interpretation of the saying which is o special importance in the modern civilised world. Anxiety is the commonest symptom displayed in the consulting-room of to-day, anxiety about health and fear of disease. But even commoner than anxiety concerning health is anxiety concerning life. Some of the difficulties against which we have to struggle are real, and very few of us can escape altogether from suffering. But many of our difficulties are purely imagin-

ary; we are afraid of what will never happen. Real or unreal, the wear and tear to which our anxieties subject our bodies are the same. To find a remedy for these ills is difficult, for it is only the minority that has succeeded in finding what is more important than all medicines, an attitude of mind which can surmount them. We live in a health-conscious age, but unfortunately our consciousness is often of the negative variety. Instead of using our knowledge so as to live as healthily as possible, we are apt to dwell on the dangers amongst which we move. We go about our daily work surrounded by the 'Fifth Columnists' of disease, but fear and anxiety, even more than micro-organisms, are our real enemies, and are more likely to be the cause of sickness. It is the hope, therefore, of the writer that in providing his readers with an elementary knowledge of the working of their bodies he will have discouraged rather than aggravated their anxieties. The human body has been wonderfully contrived, and, provided it is used properly, is well able to support most of the strains and dangers to which it is submitted. Let us see to it that we do not impose upon it the additional burden of a fearful imagination.

K.W.

HARLEY STREET, W.1
1942

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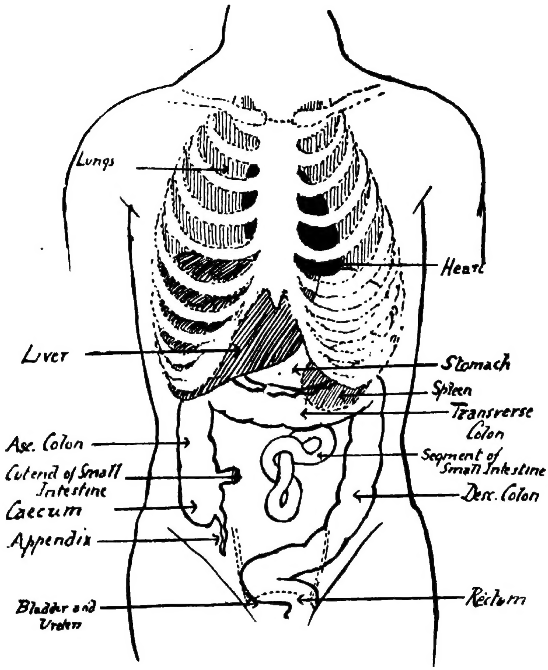


Diagram
showing the position of some of the important organs
in the chest and the abdomen.

HUMAN PHYSIOLOGY

CHAPTER I

THE CELL

PHYSIOLOGY is the science of the body, as psychology is the science of the mind. It deals with the activities of the various organs to which are delegated special functions in the body economy, and also with the means by which these various functions are co-ordinated. It cannot be too strongly insisted upon that the organs of the body do not act independently, but that the action of one is adjusted to the action of another. The health of the body as a whole depends on the harmonious working of its parts.

Before dealing with man's body and with its constituent organs, it will be useful to consider the element out of which they are built, the living cell. The cell represents the body in miniature. It may be looked upon as a working model in which we can study on a smaller scale the activities that take place in the body as a whole. The cells out of which the body is built are so small that they cannot be seen with the naked eye. On examination under the microscope, a typical animal cell is seen to consist of a mass of protoplasm, or bioplasm, surrounded by a containing membrane. Protoplasm is a term derived from two Greek words, *Protos*, first, and *plasma*, form, and it was used by Huxley to describe what we may regard as being 'the physical basis of life'. It appears to be a colourless, semi-fluid, jellylike substance. Actually, protoplasm is not homogeneous (uniform), but consists of two parts, namely, a fine network, or reticulum, and a more fluid

portion held in its meshes. A more careful examination of a cell reveals the fact that it is not made up of undifferentiated jelly, but that it possesses a definite structure. This structure is best revealed either by staining the cell with some aniline dye (such as methylene blue), or by examining it under a special lighting, known as 'dark-ground illumination'. By either of these methods the cell is seen to contain a vast number of solid particles which are aggregates of living matter (see Fig. 1). These are suspended in the more fluid portion of the cell and its internal surface is enormously increased by their presence. Since it is on surfaces that the physico-chemical reactions of life take place most readily, part of the secret of the structure of the cell is the immensity of its inner surface. It may, indeed, be looked upon as a sort of sponge in the interstices of which a hundred different chemical processes are taking place simultaneously. But the granules are not the only features that are revealed by an examination of the cell under dark-ground illumination, or by staining. Towards the centre of the cell there is a well-defined area which takes up the dye more strongly than the rest of it. This is known as the nucleus, a structure which is of the very greatest importance to the cell's life. It may be regarded as the heart and brain of its industry, the very centre of its being. The nucleus exercises control over all the cell's activities, and if it were to be removed (this delicate operation has been performed), the cell would immediately die. Each cell has at least one nucleus, which is usually round, or oval, but occasionally (as in some of the white cells of the blood) it is branched.

FIG. 1.—Illustration of a cell, showing reticuled nucleus and the substance of the cell filled with granules.

It was said that the cell is bounded by a limiting membrane, but this should be pictured as a kind of fine-meshed net

through the interstices of which there is a constant passage of material, new material passing into the cell and waste matter being eliminated from it. The cell is not isolated from the outer world by its membrane, for it is entirely dependent on this outer world for its sustenance and life. Staining a cell kills it, and in examining a stained cell we are examining a corpse in which all activity has come to an end. By the dark-ground illumination method of examination we can watch the living cell at work, and even make a cinematograph film of it. When the film is projected on to a screen the cell may appear as large as a man, and much of its structure is visible. In the middle we see the all-important nucleus looking like a large elastic-walled balloon and containing two smaller round bodies, the nucleoli, which are continually changing shape. The granules, which in the stained cell were stationary, are now seen to be streaming hither and thither in ceaseless movement. They are swept along in a primitive circulation, carrying nutriment to where it is wanted and dispatching to the cell's surface waste products for elimination.

A technique has now been found for cultivating cells taken from the body. The cultures are made in tubes similar to those used in the growing of bacteria. By such means tissue taken from a chicken embryo has been kept alive and actively growing for nearly a quarter of a century, even although a hen does not usually live for more than three or four years. In order that life may be maintained, the cultures must be transferred to new tubes containing fresh nutriment at frequent intervals. If this were not done the cells would soon die, poisoned by the waste products which they excrete. This growing of cells has given a great impetus to the study of cell life, especially when cell culture is combined with cinematography under dark-ground illumination. By employing these two methods we can study the whole life of the cell from

birth to death. We can see the birth of a new cell and watch it reach maturity and then begin to grow old, its bioplasm becoming less clear, its outline more shrivelled. And as in the jungle enfeebled animals are devoured by their fellows, so is a declining cell attacked and devoured by the scavenger cells of the body, the phagocytes. The duration of life in a cell is very short, a fact that makes it easy to observe the whole of its life history.

Although it takes millions of millions of cells to make up a human body, and although the work of these myriads of cells is co-ordinated so as to serve the ends of the whole organism, each cell is really a self-sufficient unit. Each in favourable circumstances is capable of living independently and of exhibiting the characteristics of life. Under natural conditions this does not happen, since the cells of the body have sacrificed their independence in the interests of a greater being. But in tissue cultures their independence is regained and they live their own lives. One of the problems that exercise biologists is how the work of the multitudinous cells that constitute the body is co-ordinated and made to serve a single purpose. How is a society of millions of cells governed? Occasionally the harmony between the cells is lost and a group of them, neglectful of the body's interests, live only for their own ends. This happens in cancer. A number of cells, perhaps in the breast, suddenly adopt a predatory form of life. Heedless of the interests of their neighbours, they push their way into adjacent tissues, multiplying prodigiously and acting like a number of bandits let loose in a peaceful community. Once the resistance of the law-abiding citizens has been overcome there remains only one hope for the body as a whole, the extirpation of the rebels by means of the surgeon's knife. The cancerous tissues are subjected to wholesale removal. But, fortunately, the rebels are under one disadvantage. They are more susceptible to X-rays and to the

emanations of radium than are the healthy cells of the body. The surgical attack on them may therefore be supplemented by the use of radium, or of deep X-ray therapy. These three methods of treatment, surgery, radium and X-rays, are at present our only weapons against cancer.

But to study the phenomena that constitute life it will be better to examine, not a cell artificially isolated from the body, but one that naturally leads a separate life, such as that tiny unicellular organism found in ponds, the amoeba. By examining the amoeba we shall arrive at an understanding of the activities, or functions, that characterise life. These functions may be summarised under the following headings: contractility, irritability, digestion, absorption, metabolism, excretion, respiration and reproduction. Each of these functions will be studied first in the amoeba and later in the human body.

Contractility

When examined under a microscope an amoeba, a creature one-hundredth of an inch in diameter, is seen to have the structure that has already been described. But because it leads an independent life, and is therefore under the necessity of searching for its food, its movements are more active than those of most of the cells which make up the human body. If it be watched for a short time a small elevation will be observed to arise on its surface, an elevation that finally turns into a long arm, or projection. More and more of the protoplasm of the amoeba streams into this projection, or pseudopod (from the Greek *pseudes*, false, and *pous*, foot), until it becomes the main body and what was formerly the bulk of the amoeba, a secondary projection. In this somewhat tedious fashion of throwing out a leg and then flowing into it the amoeba is enabled to move from place to place (see Fig. 2). This power of the amoeba's protoplasm to change its

form is called contractility. In the human body there are many cells, such as the white blood corpuscles, or leucocytes, which possess contractility in a high degree. Other varieties of human cells, such as the nerve cells, have very little contractile power, but those that possess it in the highest degree are the cells that make up the muscles. When the elongated muscle cells (known as fibres) contract, they diminish in length but increase in other dimensions, the change in form being brought about by a similar process to that described in the amoeba, namely, a flow of protoplasm from one situation to another.

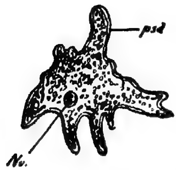


FIG. 2.—An amoeba. *Nu*, nucleus. *psd*, pseudopod.

Irritability

If we change the constitution of the fluid in which the amoeba is suspended by introducing a minute quantity of some chemical such as quinine, or if we send through it a feeble electric shock, we find that the amoeba immediately responds by rapidly throwing out a pseudopod in an effort to escape from the stimulus. If in place of an obnoxious chemical we introduce something that can be used as food, instead of trying to escape from it the amoeba approaches it. This power of the amoeba to react positively or negatively to favourable or unfavourable stimuli is known as irritability.

Irritability is a fundamental property of all protoplasm. It is the power which enables the organism to adapt itself to its surroundings. Herbert Spencer made use of this capacity of living matter to adapt itself to its environment when he attempted to define life. Life, according to him, was 'a continuous adjustment of internal relations to external relations'. It is by virtue of its irritability that living protoplasm makes

its adjustments. But for the possession of irritability an organism would soon suffer injury and die, and the greater the measure in which it possesses it, the more highly evolved is the organism. All living cells in the body are endowed with a certain amount of irritability, but the cells that possess it in the highest degree are the nerve cells. They are the most highly developed and also the most sensitive of the body cells. It must be remembered, however, that all irritable cells do not respond most actively to the same sort of stimulus. Certain cells react best to one kind of stimulus and others to another; the cells forming the retina of the eye react to light, the nerve cells supplying the ear to sound, and those of the tongue to taste. Nor is the response of the cell to the stimulus necessarily of the same nature as the response of the amoeba when irritated by quinine; a muscle cell responds by contracting, a gland by secreting, a nerve by conducting and the cells lining the small intestine by absorbing food. If we look upon irritability as an indication of life, it may be said that the intensity of life of any organism will be determined by two factors; the frequency with which changes occur in the organism's environment, and the degree of irritability it exhibits to these changes. Looked at from this point of view, it may be said that the long- but slow-living tortoise enjoys in the end no greater length of life than the short-lived but intensely irritable mosquito. Impressions and response to impressions, rather than time recorded by a clock, should be regarded as the measure by which we judge longevity. We live only so long as we have the capacity to feel and respond. In childhood impressions, and the emotions and thoughts that they provoke, are many, and our days are long and vivid. In middle and old age impressions become less vivid and our power to respond weaker, and so the days rush past us and the years contract. It may be assumed that if there were no changes in its environment the body would cease to

react and its activities would eventually come to rest in the new equilibrium of death. The hibernating animal is an example of an organism which is affected by a diminished variability in its environment as well as by reduced responses. Coiled up in some hole in the ground, the hibernating animal experiences few changes in its environment. Associated with this absence of stimulation the irritability of the animal's body is reduced to the minimum compatible with life. Should, by some accident, the irritability entirely disappear, the animal would no longer be hibernating. It would be dead.

Metabolism, or Nutrition

The cell may best be pictured as a self-running, self-sufficient chemical factory. It takes in raw material from the outside world and manufactures from this material all that it requires for the maintenance of its structures and for the work that it is called upon to perform. Sherrington, after stating that it is impossible to define life, describes it as 'an energy-system, the energy of which is directed to maintaining itself'. Looked at from this point of view, the cell may be regarded as a factory that takes in so much potential energy in the form of food and gives it back in the form of work performed; in other words, the cell (and the same applies to the body) is a device for transforming energy. Every movement made by the amoeba entails the expenditure of energy, and in order to replace what is lost the amoeba must take in more energy in the form of food. We can even calculate how much food an animal must absorb in order that it may be able to perform a given amount of work, just as we can calculate how much petrol a car will require to run a certain distance. But by rights an animal should require relatively more food than the car, for not only does it perform work, but it also makes good the wear and tear of its own machinery. These additional demands made upon it are, however, more than

counterbalanced by the fact that an animal works far more efficiently than a car does.

All those chemical processes by which food is converted into either work or structure are referred to as the cell's metabolism. Such processes may be grouped under two main headings, anabolism, or the building-up of simpler chemical bodies into those of greater complexity, and katabolism, or the breaking-down of more complex material into simpler. Generally speaking, the building-up of the food into cell structure is a process of anabolism, and the burning-up of food in order to perform work, or to maintain internal heat, a process of katabolism. The cell, and the body, have another superiority over the petrol engine in addition to greater efficiency. If there is no petrol in the tank of a car it is unable to move. When the body is deprived of food it is still able to find energy for movement and for the maintenance of heat by burning up its own structure. Fortunately it possesses tissues that are not essential to its life, and by using the fat in his body for fuel a man may survive several weeks of starvation, provided he is not also deprived of water. It is only when he has used up all the structures in his body which he can spare and is forced to draw on more vital tissues that the efficiency of the working of his body begins to decline.

Excretion

As the fumes of the petrol engine must be carried away in the exhaust if the engine is to run well, so must the cell get rid of its waste products if it is to remain healthy. We have seen that cells can be kept alive almost indefinitely in a suitable culture medium. This, however, is only so if care be taken to remove from them the waste products of their own metabolism. In growing tissues this is achieved by transplanting the cells every few days into fresh culture tubes. Should transplantation not be carried out, the cells, like fish

left in a stagnant pond, rapidly die, poisoned by their own waste products. Excretion, therefore, is an activity that is as necessary to life as is the power to absorb new food.

In a simple unicellular organism like the amoeba no special apparatus is required for the accomplishment of excretion. All that is necessary is that waste products should be able to filter through the interstices of its limiting membrane into the surrounding fluid. In a large complicated structure like the human body such primitive methods of excretion would be insufficient to secure a satisfactory draining-away of waste material. Special excreting organs are provided for this purpose. In general terms, we get rid of surplus water, urea and uric acid by the kidneys, carbon dioxide and water by the lungs, water by the skin and a small amount of waste by the bowel. All these structures may therefore be looked upon as constituting our excretory, or drainage, system. If anything goes wrong with this system the health of the body rapidly deteriorates.

Digestion

If we watch the amoeba under the microscope we will see that from time to time it engulfs, or eats, nutritive particles that happen to be floating in its neighbourhood. Once these particles have passed into the amoeba's body they appear to undergo some changes, at first becoming corroded, and then disappearing altogether. This is a simplified form of digestion. Food in the condition in which it is taken into the cell cannot be utilised by the protoplasm, either because it is insoluble and undialysable (incapable of passing through a membrane), or else because it is too complex in structure. Food must therefore undergo certain changes before it can be of any service to the cell. Broadly speaking, these changes consist in the breaking-up of the larger molecules of the food

into smaller molecules, a breaking-up that is brought about by the action of certain ferments, or enzymes. In the body this preparation of the food for the use of the tissues is carried on in a special laboratory, the alimentary canal. This is a coiled tube, nearly thirty feet in length, which comprises the mouth, oesophagus, stomach, small intestine and large intestine. In order to reach the other cells of the body the soluble products of digestion must pass first through the walls of the alimentary canal and then through those of the blood vessels, and thus gain the blood stream. The process by which digested food is transferred from the free surface (lumen) of the alimentary canal into the blood stream is called absorption. The alimentary canal is thus responsible for two functions, digestion and absorption.

Respiration

The energy necessary for the body's activity is supplied by the burning-up of food products, in other words, by their oxidation, just as the energy of a car is supplied by the oxidation of its petrol. In order that this combustion may take place the body requires, first, a plentiful supply of oxygen, and second, a means of getting rid of the carbon dioxide produced by the oxidation. The process by means of which these two needs are satisfied is known as respiration. Respiration is a function that is as necessary to the life of a cell as it is to that of a body. Although no movements of breathing can be observed in the amoeba, an interchange of gases is going on without ceasing. All the time the oxygen dissolved in the surrounding fluid is being absorbed through its limiting membrane and the carbon dioxide is passing back into the fluid. Every cell of the human body is equally dependent on an interchange of these two gases, and the more active the cell, the more insistent is its need for a liberal supply of oxygen. As an example of this may be cited one of the most

active cells in the body, the nerve cell. The brain cell is particularly dependent on a good supply of oxygen. It has been noted by all climbers and aviators that the brain becomes less active at high altitudes, where, owing to the rarity of the atmosphere, the intake of oxygen is diminished. Should the pressure of oxygen in the surrounding atmosphere fall below a certain level the brain cells are no longer able to work and a man becomes unconscious.

It is obvious that with so much need of oxygen a human body could not rely, like the amoeba, on absorption through the skin. It is therefore provided with a special bellows apparatus, the respiratory system, by means of which a plentiful supply of oxygen and a rapid disposal of carbon dioxide are assured.

Reproduction

This, like respiration, is a function that is characteristic of all living things, a function which distinguishes them from inanimate matter. In the amoeba and in the cells of the body, reproduction would at first sight appear to be a simple process. All that happens is that the cell forms a partition down the middle and then breaks into two halves. Actually, cell division is a far more complicated affair than it appears to be. The first sign that a cell is about to divide is in the nucleus, a structure which not only initiates, but exercises control over, the whole process of cell division. When a cell is stained the nucleus is seen to be made up of twisted filaments of a darkly-staining protoplasm. In its neighbourhood we can sometimes make out two little bodies, called the attraction spheres, which are of great importance in the division of the nucleus. When the cell is about to divide, these two spheres start to move towards opposite poles of the nucleus. The next thing that happens is that between them appears a series of lines, forming with the two spheres a delicate

spindle-shaped structure (see Fig. 3). The twisted filament of the nucleus then proceeds to break up into a number of short V-shaped pieces, known as chromosomes. The number of chromosomes into which the nucleus divides is definite for any given animal, but varies in different species. Some animals are provided with many chromosomes and others

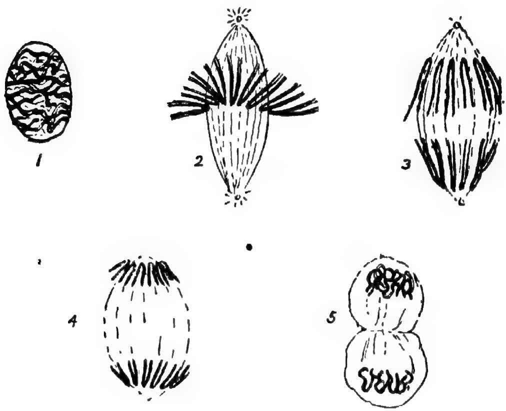


FIG. 3.—Diagram illustrating cell division.

with few, but whether they be many or few the number is always the same for any given species. Another interesting feature of the chromosomes is that they are believed to be the bearers of the genes, that is to say, the structures which are the physical basis of inherited characteristics. If the twisted filament of the nucleus which breaks on cell division into chromosomes be likened to a tangled rosary, the genes could be regarded as the beads strung along the rosary. The chromosomes, which are at first arranged around the

equator, or broadest part of the spindle, then split lengthwise, each chromosome giving rise to two. Each one of a pair travels along the lines of the spindle to reach an opposite pole. By joining together they eventually form two nuclei at the extremities of the spindle. Now that the nucleus has successfully divided, the rest of the cell does likewise. A partition forms across the middle of the cell and this breaks into halves, each half possessing its own nucleus. This elaborate process of cell division (it has been much simplified in the above description) is known as cell mitosis.

The various activities of the cell that have been described under the headings of irritability, contractility, digestion, absorption, anabolism, katabolism, excretion, respiration and reproduction are the characteristics that distinguish living matter from non-living. When we ascend from lowly unicellular organisms to the complex structure of the higher animals we find there also the same fundamental processes at work. But because specialisation has taken place in the higher animals, the functions performed by the single cell of the amoeba have been delegated to organs especially evolved for that purpose. Irritability becomes the special function of the central nervous system, digestion and assimilation are assigned to the alimentary canal, respiration is undertaken by the lungs and reproduction by the genital system. It is by specialisation that the complex multi-cellular organisms are distinguished from the more primitive forms of life. This specialisation affects not only the general structure of the body, but also the elements out of which that body is formed, the cells. Although some of the cells of the human body resemble the amoeba, they are in the minority. The vast majority of human cells have undergone profound modifications in order to fit them for their special duties. The muscle cells have become elongated and have developed in a very high degree the function of contractility. The nerve cells

have thrown out an arm of great length and have become highly irritable so that they may be capable of carrying the nervous impulses. Bone cells have acquired the capacity to collect from the blood calcium and to deposit it around themselves to form bone, in the same way that the coral polyp forms an atoll by building around itself walls of chalk. Glandular cells specialise in forming enzymes, and the cells that line the small intestine in absorbing food. Although each cell is a self-sufficient entity, and in certain circumstances has the capacity to live alone, the functions of all are co-ordinated to the greater purposes of the body as a whole.

Tissues

When a single organ is examined microscopically it can be divided into several parts, the parts being composed of collections of similar types of cell. These collections of cells, the material out of which organs are formed, are called tissues. A tissue may therefore be defined as a group of similar cells. In works on physiology tissues are usually classified under four main headings; (1) epithelial tissue; (2) connective tissue; (3) muscle tissue; (4) nerve tissue.

Epithelial tissue is covering tissue. It is composed of cells closely arranged, and containing very little intercellular, or cementing, substance between them. Their shape may be flat, or scale-like, thicker, or what is known as cuboidal, or very deep, forming what is called columnar epithelium. These variously shaped epithelial cells may be arranged in a single layer or in several layers. The first we describe as simple epithelium; the second as stratified epithelium. Simple epithelium is found lining the air cells of the lung, forming the capillaries, and covering the surfaces of serous membranes, such as the peritoneum and the pleura. Stratified epithelium is the commonest epithelial tissue in the body. It forms the outer layer of the skin, the surface of the cornea of

the eye, the mucous membranes and the glands. In general, the functions of epithelial tissue may be said to be those of protection, secretion, absorption and excretion.

Connective tissue is the most widely spread of all the tissues in the human body, and its function is what its name implies, to connect and to support. Many different varieties are included under this heading. Connective tissue differs from epithelial in that the intercellular substance is very abundant in relation to the cells, and modifications of this intercellular substance account for some of the differences found in connective tissue. The commonest type of connective tissue in the body is what is called fibrous tissue, the material out of which scars are made. This, as its name implies, is made up of fibres embedded in a soft structureless ground substance. The fibres are exceedingly minute and are grouped together in bundles (see Fig. 4). They are of great strength and pliability, and form tendons and the ligaments by means of which the bones are held together. Fibrous tissue is usually subdivided into three varieties: areolar, fibrous and elastic. They differ chiefly in the nature of the fibres found in the intercellular substance. Fibrous tissue proper is composed of dense white fibres grouped in parallel bundles which communicate freely with each other. The tissue is very compact. In areolar tissue the bundles of fibres run in every direction, and the tissue is more loosely woven. This is the most abundant of all the varieties of connective tissue. It forms sheaths round the muscles, nerves and blood vessels, is found in the walls of the alimentary, respiratory and genito-urinary tracts, and generally speaking it is the tissue that

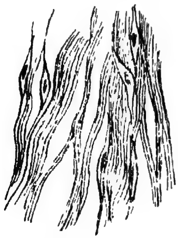


FIG. 4.
Connective tissue.

holds the body together. Elastic tissue contains, in addition to the ordinary fibres, a large number of yellow elastic fibres. It is found in the walls of the bronchioles, the arteries and in the vocal cords. What we know as fat is a form of connective tissue in the cells of which a great number of fat globules has accumulated. As well as being a storehouse for food, fatty tissue provides an excellent packing for delicate organs. On the surface of the body it forms a layer which is of use in conserving body heat.

Cartilage may also be regarded as a form of connective tissue in which the ground substance is replaced by a firmer material that gives it greater rigidity. When calcium is deposited in the ground substance of cartilage it is no longer cartilage but bone. Cartilage is indeed the precursor of bone in the body, and in a young child many of the bones of an adult are still in the preliminary stage of cartilage. Gradually as the child gets older more and more calcium is deposited in them. The preponderance of cartilage in the body of a child accounts for the fact that it is much more resilient than that of an adult. It also explains the liability of children to the injury known as 'greenstick' fracture. Instead of breaking like a dry stick, the bone bends like a green one.

Lymphoid, or adenoid, tissue is a special form of areolar tissue rich in cells as well as fibres. It is found in the lymph glands, the tonsils and the spleen. The other members of the four main groups of tissues, muscle tissue and nerve tissue, will be dealt with in Chapters VII and VIII.

CHAPTER II

THE DIGESTIVE SYSTEM

In speaking of the cell it was said that digestion was the process by which the food is prepared for the use of the tissues, larger molecules being broken up into smaller. As a result of this breaking-up the food can be utilised by the body for its particular needs. It is now necessary to study in greater detail how this process is carried out in the human body.

The system of channels through which the food passes from its entry in the mouth to the final stage of the excretion of the indigestible part of it at the anus is termed the alimentary canal. Lying in the mucous membrane or lining of this canal is an immense number of small glands pouring out digestive juices, or enzymes. In addition to the multitudinous digestive glands existing in the walls of the canal there are two large glandular organs lying outside it and pouring their secretion into it by their ducts. These are the liver and the pancreas.

The alimentary canal commences at the mouth, in which the food undergoes its first preparation for absorption by means of the saliva. Before discussing the action of the saliva on the food it will be helpful to describe the glands that form it, since in structure they are essentially like all the other glands in the body. A description of the salivary glands will therefore be of general application to other glandular structures. Broadly speaking, a gland is a pocket lined by special cells which form, or secrete, a ferment, or enzyme (see Fig. 5). This secretion passes from the cells on to the free surface or lumen of the gland, and from thence by means of its chan-

nel, or duct, finds its way into the alimentary canal. The most elementary form of gland is a simple pocket, but the majority of glands are branched. The secretions from all the branches pass into the duct by which they eventually reach the alimentary canal. Most of the salivary glands are of this branched variety and they are collected together into three main groups. The largest of these groups constitute the parotid glands, which are situated just beneath the skin in front of each ear. Their ducts open inside the mouth, opposite the upper molar teeth. It is these parotid glands which become inflamed and swollen in the epidemic disease known as mumps. The next largest collection of salivary glands are situated close to the inner side of the jaw, near the tongue. They are known as the submaxillary glands. The third pair, or sublingual glands, lie, as their name implies, underneath the tongue, their ducts opening, together with those from the submaxillary glands, on the floor of the mouth.

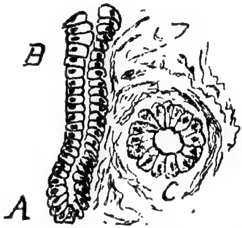


FIG. 5.—Microscopic section of a simple gland, such as a salivary gland. *A* and *B* show one in longitudinal section, and *C* one in cross section.

The entry of food into the mouth is followed by an immediate flow of saliva into it, a flow that is brought about by reflex action. Even the smell or the sight of food will produce this automatic secretion of saliva. Between meals only enough saliva is secreted to keep the mouth moist. The nature of the reflex action which brings about a great increase in saliva during mealtimes will be studied more fully when dealing with gastric digestion.

The main constituent of the saliva is a ferment, or enzyme,

which is called ptyalin. This acts only on the starchy portions of the food, converting insoluble starch into soluble sugar. Food, as will be seen later, is of three kinds: carbohydrates (of which starch is an example), nitrogenous food, or proteins (such as white of egg), and fats. The saliva acts only on carbohydrates, having no effect on proteins and fats. It contains a small quantity of mucus and enough alkaline salts to render its reaction alkaline. But food in the mouth is subjected not only to the chemical changes brought about by the action of a ferment, but also to the physical action of mastication. As a result of this it is divided into small masses and then, thoroughly mixed with mucus, formed into a ball ready for swallowing. Thorough mastication of the food is of great importance to digestion, and when, through loss of teeth or the habit of bolting, mastication is insufficient, extra work is thrown on the stomach. Faulty mastication is a frequent cause of indigestion, and unfortunately the food of civilised man can generally be swallowed before it has been properly chewed.

Deglutition, or the act of swallowing, is really a very complicated movement brought about by the co-ordination of a great many different muscles. One of the reasons for its being complicated is that it is necessary to ensure that the food, when it has reached the back of the tongue, shall enter the oesophagus and not pass by mistake into the larynx or to the back of the nose. To shut off the nasal cavities the soft palate is drawn upwards so as to close the nasopharynx. To prevent the food entering the larynx there is a special structure at the back of the tongue, known as the epiglottis. This is a flap of cartilage covered with mucous membranes which projects backwards from the base of the tongue so as to overhang the entrance to the glottis. At the moment of swallowing the whole of the Adam's apple containing the glottis is drawn upwards under the epiglottis. Once the food has traversed

this critical stage in its journey, it is grasped by the oesophagus and carried by a wave of muscular movement towards the stomach. In human beings gravity assists its descent, but in an animal, such as a horse, the contractions passing along the oesophagus are sufficient to carry food and drink in a direction opposite to that of gravity. If a horse be watched when drinking from a pail on the ground, wave after wave of movement will be seen to pass along the lower part of its neck forcing fluid in the direction of its stomach.

On leaving the oesophagus the food enters the stomach, the most dilated portion of the whole of the alimentary canal. This organ lies in the upper part of the abdomen, just below the diaphragm, or muscular partition which separates the abdomen from the chest (see Frontispiece). The stomach lies underneath the heart but separated from it by the diaphragm, and the nearness of these two organs explains the frequency with which patients complain of heart disease when actually they are only suffering from an excess of wind in the stomach. The stomach is shaped like a pear, its broad end lying to the left under the ribs, and its narrow end (where it joins the small intestine) at the lower level on the right side (see Fig. 6). It is a highly muscular organ, especially in herbivorous animals and in birds, whose stomachs are called upon to do much grinding. Not only does the stomach digest food, but it also acts as a place of storage for it. In the human adult its capacity may be anything from three to five pints. This enables us to take in enough food in two or three meals to last us for the whole of the day. From the storehouse of the stomach small portions of digested food pass on at intervals to the intestines. The capacity of the stomach to store food and to remit it from time to time in convenient quantities to the intestines is of great practical importance. A patient whose stomach has been removed—and this operation, although a serious one, can be performed—is com-

pelled to partake of many meals during the course of a day, at each of which only a very limited amount of food can be eaten. In order that the food may be retained as long as necessary in the stomach, and not regurgitate into the oesophagus, or else be passed too quickly into the intestines, it is provided with two sphincters, or circular bands of muscle surrounding its inlet and outlet. The sphincter at the cardiac end where it joins the oesophagus opens from time to time to admit food, and that at the pyloric end where it joins the intestine does likewise to allow the escape of the food that has been sufficiently digested.

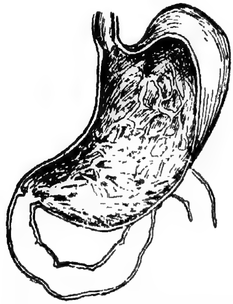


FIG. 6.—The human stomach and duodenum. The front wall of the stomach has been removed in order to show the mucous lining thrown into folds.

The digestive action of the stomach secretion is much more powerful than that of the saliva, and because it contains several enzymes, has a wider range of action. Three digestive processes take place in the stomach. (1) The digestion initiated by the saliva continues until the hydrochloric acid secreted by the stomach brings it to an end. Ptyalin, it will be remembered, can only act in an alkaline medium, whilst pepsin (the chief enzyme secreted by the stomach) requires for its action one that is acid. Gradually the hydrochloric acid formed by the stomach permeates the food and brings salivary digestion to an end, initiating digestion by pepsin. This ferment acts on the nitrogenous foods, or proteins. As the insoluble starchy foods are converted by ptyalin into soluble sugar, so are proteins (such as egg albumen) converted into dialysable (capable of passing through a mem-

brane) products (such as peptone). (2) The second important enzyme secreted by the stomach is rennin, a ferment capable of bringing about the clotting of milk. The commercial rennet used in preparing junket is extracted from the stomach of a calf, and its action is similar to that which occurs in gastric digestion. (3) In addition to the action of these two ferments a certain amount of digestion is brought about in the stomach by micro-organisms which split carbohydrates into gases and organic acids, and more particularly into lactic acid. As in the case of ptyalin digestion, the activity of micro-organisms is eventually brought to an end by the increase of hydrochloric acid in the stomach. Micro-organisms are unable to work in high concentrations of acid.

The Control of Gastric Secretion

Our knowledge of gastric secretion has been advanced by the work of the Russian physiologist Pavlov, but long before his time Beaumont made observations on a Canadian hunter, Alexis St. Martin, who was accidentally wounded in the stomach by gunshot (1822). The wound healed, leaving an opening, or fistula, through the abdominal wall into the stomach. Through this opening the interior of the stomach could be observed by Beaumont, and juice collected from it. But because it was mixed with food Beaumont could never obtain any pure gastric secretion for analysis. Pavlov achieved this by dividing the stomach of a dog into two parts, so that after sewing the walls together the dog had two stomachs; a large one connected with the oesophagus and intestines, and a smaller artificial stomach having no connections with the alimentary canal but opening on to the skin. This provided him with pure gastric juice uncontaminated with food. Pavlov found that it was sufficient to show the dog a piece of meat in order to provide a plentiful supply of juice. In whatever manner the dog's appetite was aroused, by

sight, by smell or by taste, the result was a flow of gastric juice. Not only was secretion provoked reflexly through the special senses, but also by introducing food, unknown to the dog, into the artificial stomach. Later by another series of experiments Pavlov showed that gastric secretion could be induced by a stimulus that ordinarily has no connection with the taking of food. By ringing a bell, or by setting a metronome going just before the animal was fed, the dog learnt to associate this stimulus with the idea of a meal, and after a time it secreted juice whenever the bell was rung or the metronome started. Pavlov carried his experiments even further. When the animal had learnt to secrete juice with the metronome ticking at a rate of, say, 100 to the minute, he set it going at 50 to the minute and took the meat away. In time secretion stopped whenever the metronome beat at the lower rate and started again when it was put back to the higher.

Another observation of great interest made by Pavlov was that the offspring of animals which had been taught to respond in this way to an artificial stimulus learnt their lesson more rapidly than their parents had. This fact suggests that, contrary to the teaching of Weismann, acquired characteristics of the parents may be transmitted to the offspring.

Advances in medical technique now permit us to observe the interior of the stomach without any necessity of making an artificial opening in it. By means of a gastroscope introduced through the oesophagus the stomach can be directly inspected and an abnormal condition, such as an ulcer, diagnosed. The prevalence of gastric troubles at the present day is probably due to a variety of factors, amongst others errors in diet, septic conditions of the mouth, faulty mastication and disturbances of gastric functions produced by anxiety. Some authorities believe that heavy smoking may also be a factor in the causation of ulcer, but it is more likely

that over-smoking is merely a sign of the nervous strain under which most people are living.

It is easy to see why the taking of food should cause pain and sometimes vomiting in a patient who is suffering from a gastric ulcer. So long as the stomach is empty the ulcer remains at rest, but with the first mouthful of food acid juices are poured into its interior and its walls are thrown into activity. For this reason pain occurs immediately the patient begins to eat, whilst in the case of duodenal ulcer, pain is deferred for two or three hours, that is, until that time when the contents of the stomach are being emptied into the duodenum. Our knowledge of the constitution of the gastric juices provides us with a scientific basis for the medical treatment of the various forms of dyspepsia. A deficiency of gastric juice is treated by means of extracts of pepsin and weak hydrochloric acid; an excess of acid (hypochlorhydria) by the taking of alkalis (bicarbonate of soda, bismuth, magnesia, etc.). Since food 'fixes' and itself neutralises free hydrochloric acid in the stomach, acidity is usually temporarily relieved by the taking of food.

The Movements of the Stomach

When the stomach is empty its muscles are contracted. The capacity is therefore much reduced and its lining membrane thrown into folds. With the swallowing of food and the relaxation of the cardiac sphincter movements begin, at first gently, but later with increasing vigour. These movements take the form of waves of contraction beginning high up in the fundus, or body of the stomach, and travelling towards its narrow end, or pylorus. By feeding a patient with bismuth, and afterwards examining him under X-rays, these movements may be studied. Successive waves of contraction are seen to pass along the stomach at intervals of about twenty seconds (see Plate I). By these churning movements

the food is disintegrated and well mixed with the gastric juice. After they have continued for a time, the pyloric sphincter is seen to relax, thus allowing small quantities of digested food to enter the first part of the small intestine, which is known as the duodenum. So long as the food remains solid the sphincter will not relax, or if it does so in error it contracts again violently, causing stomachache. Different foods must remain for longer or shorter periods in the stomach; proteins, for example, are retained for twice as long as carbohydrates, and fats for an even longer period. All these movements are co-ordinated by means of the central nervous system. That the stomach is under the control of the central nervous system and that its movements can be affected by emotional states is shown by the fact that an unpleasant sight may cause vomiting.

The time taken for the emptying of the stomach varies enormously with the nature of the food that has been ingested. With a meal of gruel it is usually empty in two and a half hours, but after the barium or bismuth meal given before an X-ray examination six hours may be required before all the opaque substance has passed on into the intestine. Of the many conditions that may influence gastric digestion apart from the nature of the food swallowed two may be cited as being of particular importance; good appetite and good cooking. The zest with which food is taken influences the activity of the gastric glands. A meal eaten with relish is more likely to be well digested than one taken in a state of excitement or mental depression. ('Better is a dinner of herbs where love is, than a stalled ox and hatred therewith': Proverbs xv. 17.) Good cooking, also, has a beneficial influence on digestion. Cooking not only renders the food more appetising but helps to break up the cellulose walls of vegetables and allows the gastric juices to get at the more digestible residuum. In the case of food derived from

animals, fat may act like cellulose in preventing the juices from reaching the more digestible portions of the meat. For this reason fatty food, such as pork and goose, is less easily digested than flesh containing less fat, such as beef and chicken. The time-honoured advice not to eat when one is much fatigued is supported by physiological observation; fatigue, anxiety and violent exercise all interfere with digestion.

The Duodenum

This is about ten inches in length and is of particular importance because it is into this first part of the intestine that the ducts coming from both the liver and the pancreas enter. When the food in the stomach has been sufficiently liquefied it is expelled as what is known as chyme, into the duodenum. Here two fluids are speedily poured upon it, both of which are alkaline, the pancreatic juice and the bile. Whereas the saliva acts only upon carbohydrates, the gastric juices upon proteins and caseinogen (the nitrogenous part of milk), the pancreatic juice acts upon all three varieties of food, carbohydrates, proteins and fats. This last-named secretion may be regarded as one of the most important of the digestive juices and must be studied in detail.

The Pancreas

This gland, known to butchers as the sweetbread, is about six inches long and one and a half inches wide. Lying just behind the lower edge of the stomach, its duct, after uniting with the common bile duct from the liver, opens into the duodenum about three inches below the pylorus. As well as providing an external secretion, the pancreas also forms an internal secretion which is of the very greatest importance to the carbohydrate metabolism of the body. This is the insulin which is so largely used in the modern treatment of diabetes.

Banting's great discovery was that this could be best obtained by first ligaturing the pancreatic duct so as to put out of action the external activity of the gland and thereby to increase its output of internal secretion. But it is with the external secretion of the pancreas that we are at present concerned, and the study of the internal secretion of the pancreas will be deferred to a later chapter. Pancreatic juice contains three different ferments, trypsin, steapsin and amylopsin. These act on proteins, fats and carbohydrates respectively, and they will be considered separately. Trypsin acts upon the proteins that have not already been digested by the gastric juices. It also carries the work of protein digestion a little further than does the stomach. Steapsin splits fat into its two component parts, fatty acids and glycerine. It will be remembered that during World War I, when the Germans were short of glycerine out of which to manufacture the explosive nitroglycerine, there was a rumour that they were manufacturing it from corpses by breaking down human fat. Steapsin affects this splitting of fats into fatty acids and glycerine and thus prepares fat for absorption. The third ferment, amylopsin, like the ptyalin of saliva, converts starch into sugar. The pancreas, therefore, acts on all three types of food: by its trypsin on nitrogenous foods or proteins, by its amylopsin on carbohydrates, and by its steapsin on fats. Having considered pancreatic digestion, it will now be necessary to study the second secretion that is poured into the duodenum, namely, the bile.

The Liver

The liver is the largest glandular organ in the body. It lies on the right side of the abdomen just below the diaphragm, and is responsible not only for the formation of bile but for a great deal of work in the general metabolism of the body. Attached to its under surface is a small pear-shaped storage

place for bile, the gall-bladder. The bile leaves the liver by two channels, one going to the gall-bladder, where a certain quantity of bile is stored, and the other opening into a duct which, after receiving that from the pancreas, enters the duodenum.

The bile is a yellow viscous fluid, with an intensely bitter taste. Its constitution is extremely complex. Bile contains the following ingredients: water, inorganic salts (especially sodium carbonate), mucous material (which gives it its great viscosity), bile pigments, bile salts and a fatty substance called cholesterol. The last-named ingredient of bile plays no part in digestion, and because it is very insoluble in the fluids of the body it is readily thrown out of solution. It is this substance which gives rise to gall-stones, a common trouble in middle life. So long as the gall-stones remain in the gall-bladder few symptoms are caused, but should they enter the bile duct and cause obstruction the result will be a severe attack of biliary colic, associated in many cases with jaundice. The yellow colour of the skin in jaundice is due to the obstructed bile pigment being absorbed into the blood, carried throughout the body and deposited in the deeper layers of the skin.

Some biles are yellow and others are green, the difference in tint being due to the relative proportion in them of two pigments, bilirubin and biliverdin. Since the value to us of bile pigments is unknown, they are regarded as being excretions. Bile salts play a large part in the digestion of fats. Although bile contains no important ferment, it aids digestion in other ways. As previously stated, the chyme on leaving the stomach has a strong acid reaction, which, unless it were modified, would prevent the action of the important enzymes present in the pancreatic juice. The neutralisation of the acid chyme is brought about by the carbonates in the bile. In addition to this, the bile, by virtue of its bile salts,

gives great aid in the digestion and absorption of fats by dissolving them. Fatty acids are insoluble in water, but are soluble in a solution of bile salts. It is also believed that bile lessens putrefactive processes in the intestines. Finally, the mucous material in the bile acts as a lubricant and thus assists the propulsion of the food through the intestines.

The Small Intestine

Mixed with the bile and the pancreatic juice the chyme passes along the small intestine, where it is submitted to the action of a ferment formed in its walls, the succus entericus. This intestinal ferment reinforces the action of the pancreatic trypsin and carries the digestion of proteins to a further stage. The food has now been brought to a condition in which it can be absorbed through the walls of the intestine into the blood stream. Absorption is one of the important functions of the small intestine, but before considering the means by which absorption is brought about it will be advisable to consider another question. How is it that the stomach and intestines are not themselves digested by the potent juices that they form? It is only because they are alive that this catastrophe does not happen. If the circulation of a part of the stomach is interrupted sufficiently long to damage the vitality of its walls, the gastric juices begin to digest it. The subject is a complicated one, but the consensus of opinion is that the walls of the stomach and intestines form antibodies which protect them against their own ferments, in the same way that the tissues of a patient who has recovered from smallpox form antibodies which will protect him for the rest of his life from again being attacked by that disease.

In order to increase the surface from which digested food may be absorbed, the mucous lining of the small intestine is thrown into many transverse folds. These folds are studded with millions of microscopic hair-like structures resembling

the tentacles of a sea anemone, which are known as villi. The velvet-like texture of the mucous membrane of the small intestine is due to its being covered with this 'pile' of villi. Running down the centre of each villus is a blind duct (lacteol) which communicates with larger ducts that finally end in a single channel, called the thoracic duct (see Fig. 7). The thoracic duct is part of a system, known as the lymphatic system, which will be studied later. Thoracic, of course, means belonging to the chest, a term that is given to this channel because it ascends from the abdomen through the chest, to empty itself finally into the left subclavian vein near the heart. The function of this duct will shortly be described.

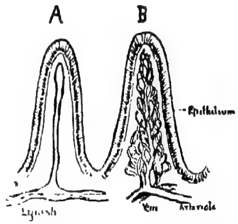


FIG. 7.—Diagram of two villi. In *A* is seen the central lacteol, joining at its base other lymph vessels. *B* shows the network of capillaries, joining at its base an artery and a vein. (After Buchanan's *Anatomy*.)

The absorption of food products into the blood stream occurs by two routes, a direct and an indirect. By the direct route certain ingredients are absorbed directly into the small blood vessels supplying the villi. By the indirect route other ingredients find their way into the blind duct in the centre of the villus, and thence are carried via the thoracic duct into the left subclavian vein. Water, carbohydrates and the broken-down proteins reach the blood stream by direct absorption, and it is in order that they may be capable of passing through the intestinal mucous membrane and the walls of the capillaries that starch has had to be converted into sugar, and proteins into simple bodies called amino acids. Fats take the indirect route, passing through the mucous lining in tiny drops which eventually find their way

into the central blind channel (lacteol) of the villus. If the intestines of an animal be examined after a meal of fat, it will be seen that the whole network of ducts, which eventually reach the thoracic duct, is white with drops of fat.

Although by far the greater part of food absorption takes place in the intestine, a small amount of water may reach the circulation from the lining of the stomach and from the large intestine. Even a little sugar is capable of being absorbed through the latter, and advantage is taken of this fact to nourish patients who, because of vomiting, are unable to be given fluids in the ordinary way. The giving of nutrient enemata is a common practice in medicine, the enemata usually taking the form of water in which is dissolved glucose. Stimulants and certain drugs may also be administered in a similar manner, amongst others brandy, chloral, bromides, paraldehyde and the modern anaesthetic avertin.

Like the stomach, the intestines are in constant movement, the movement being necessary for mixing their contents and for their propulsion through the body. The presence of food in the intestines itself provides the stimulus to this movement. When we observe it carefully we find that the movement consists essentially of a contraction of circular fibres above the intestinal contents and a dilatation of the fibres below them, so that they are propelled along the intestines at a rate of about an inch per minute. By means of these rhythmic movements (known as peristaltic movements) the liquid contents of the small intestine eventually pass through some twenty feet of bowel till they reach the large intestine (see Frontispiece). The entrance to this is guarded by a special band of muscles, called the ileo-colic sphincter. When the food arrives at this point the sphincter relaxes so that it may pass into the caecum. This, in a man, is a comparatively unimportant part of the large bowel, but in a herbivorous animal, such as a rabbit, it is a very bulky struc-

ture. The caecum is interesting because to it is attached a small appendage that has become a household word, the vermiform appendix. Anatomists regard this as a more or less useless relic of the bulky caecum found in herbivorous animals. Unfortunately it often retains within it a small cavity in which food particles may lodge and give rise to trouble. It must be confessed, however, that this danger has been very much exaggerated and that only in a small percentage of cases is an attack of appendicitis caused in this manner. Much discussion has centred round the causation of appendicitis, and everything from wrong feeding to cooking in enamelled saucepans has been blamed for this disease. It would be better to admit that so far the medical profession has found no satisfactory explanation for the frequency of this trouble at the present day.

From the caecum the residue from the food passes up the ascending colon to the level of the liver, and thence by the transverse colon to the left side of the body where it enters the descending colon. In the large intestine anti-peristaltic, as well as peristaltic, movements occur. The object of this retrograde movement is, no doubt, to prevent a too hurried passage of the contents along the colon and to allow time for the absorption from the bowel of a large proportion of the water contained in the food. The lining of the colon, unlike that of the small intestine, is not thrown into folds, and this being so, and the surface area being less, greater time is required for absorption. In the upper part of the left side of the abdomen, at the level of the spleen, the food, now of very little nutritive value, enters the descending colon. When it has traversed this it has arrived at the rectum, the lowest six inches of the large bowel. It is still a disputed point whether the faeces (the indigestible residue of the food together with waste products) enter the rectum prior to defaecation.

The length of time taken by food to pass through the

whole alimentary canal varies so largely in different individuals and under different conditions that no definite figure can be given for it. Certain investigators have reported that if a quantity of small brightly coloured beads are swallowed, 15 per cent of them are passed at the end of the first day, 40 per cent on the second day, 15 per cent on the third day and 10 per cent on the fourth day. The rapidity of evacuation of the bowels depends partly on the nature of the food, partly on lubrication and partly on the amount of exercise taken. When the diet includes a large amount of vegetable food rich in cellulose, two, or even three, evacuations may occur in a day. On a diet consisting mainly of milk or meat evacuations are reduced, owing to the small bulk of indigestible residue that is left. The fact that in many modern diets the indigestible residue is of insufficient bulk to stimulate the activity of the bowel partly accounts for the prevalence of constipation. For this reason physicians usually recommend the taking of more vegetables, or even prescribe some substance like bran, or agar, which swells up with moisture and provides the bulk that is lacking. Another method of treating constipation is to supplement the natural lubricating medium of the bowel with liquid paraffin. Both of these methods are preferable to the taking of purgatives, since the majority of these act by irritating the bowel. Purgative salines have the advantage of causing very little irritation. They act by attracting water into the bowel, thereby rendering the faeces more fluid and at the same time adding to their bulk. Lack of exercise resulting in a poor condition of the abdominal muscles is probably responsible for much of the constipation from which town dwellers suffer. The use of appropriate abdominal exercises will often result in a cure of this type of constipation.

In the converse condition, diarrhoea, the contents of the small intestine are forced into the colon at an abnormal rate.

This seriously curtails the digestion and absorption of food, so that persistent diarrhoea is likely to lead to malnutrition. Excessive peristalsis may be caused by ulceration of the bowel (as in typhoid fever and dysentery), by the fermentation or putrefaction provoked in the bowel by eating unripe fruit or bad food, and by infection of the bowel with pathogenic (disease-causing) organisms (as in cholera). It is because castor oil promptly empties the bowel and gets rid of fermentation products quickly that it is sometimes used as the first step in the treatment of diarrhoea.

In a work of this kind it is impossible to follow the course of the food from the time of its absorption till its disappearance into the structure of the body or its expenditure as energy. All that can be attempted is to give a general indication of the nature of body metabolism. In these chemical processes the liver plays an important part. We will therefore return to a consideration of this organ.

The Physiology of the Liver

The liver may be looked upon as being an immense lobulated gland. It lies mainly in the right upper quadrant of the abdomen, just below the diaphragm, and extends over the midline of the body on to the right side. Its general appearance and consistency are familiar to those whose knowledge of anatomy is limited to the sight of various organs displayed in butchers' shops. By 'lobulated' is meant that the liver is made up of an immense number of lobules, or small packets of gland substance, about one millimetre in diameter. When examined under the microscope each lobule is seen to consist of a number of polyhedral cells loosely packed together around a particular arrangement of blood vessels and bile capillaries. The arrangement of the blood vessels is as follows. The portal vein, bringing blood from the alimentary tract to the liver, on entering that organ

divides first into right and left branches and then breaks up into innumerable venules which run between the liver lobules. These are the inter-lobular veins, which in turn give rise to a network of capillaries within the lobule itself. Blood, or rather plasma, from these capillaries percolates through spaces between, and even within, the liver cells, spaces so fine that blood corpuscles are too large to pass along them. These fine spaces converge towards, and connect up with, a vein situated in the centre of the lobule, the intralobular vein. Blood from the intralobular veins eventually passes into the hepatic veins and thence into the inferior vena cava. The arrangement of the other system, the bile capillaries, is somewhat similar to that of the blood vessels which we have just described. Starting as minute channels between and within the liver cells, the bile capillaries empty themselves into the inter-lobular capillaries (lying between the lobules) and from thence into the bile ducts (see Fig. 8).

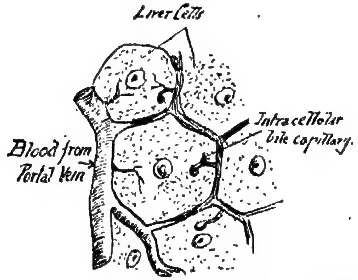


FIG. 8—Hepatic cells (diagrammatic), showing intracellular bile capillary and blood supply.

There exist in the liver, therefore, two fine networks, one for the blood and the other for the bile. It is small wonder that with all these vessels in it a liver when cut into exudes blood and bile freely. Instead of being looked upon as a solid organ

t should be visualised rather as a fine sponge-work of cells in the interstices of which lie blood and bile. Having described the minute structure of the liver, it is now possible to consider its various functions.

Bile, as well as being an aid to digestion, provides a means for the excretion of certain waste products. The two bile pigments, bilirubin and biliverdin, are themselves really waste products derived from the haemoglobin or red-coloured matter liberated by breaking down blood corpuscles. It is also part of the liver's work to neutralise and to get rid of any poisonous products that may have been absorbed into the portal vein from the alimentary canal. Even bacteria may be filtered off from the portal blood by the liver. It is always extremely active in cases of poisoning, and in all police investigations of deaths believed to be due to poisoning great attention is paid to the state of the liver. Should considerable doses of arsenic have been administered during life, some of it can always be recovered from the liver. Similarly when a patient dies from an overdose of the arsenical preparations used in the modern treatment of syphilis—a rare event at the present day—degenerative changes are usually found in the liver. Frequently it suffers in its struggle to deal with poisons, whether they be administered from without, or result from faulty body metabolism. Cirrhosis of the liver is an example of this. Cirrhosis is a state of degeneration of the liver which may be the result of alcoholic excesses over a number of years. Fortunately, this particular trouble has become less common in the present century.

It was stated that all starchy foods are absorbed from the alimentary canal into the blood stream in the form of sugar. In spite of this absorption the sugar content of blood remains constant even after a large carbohydrate meal. During starvation or on a full diet the blood sugar in the general

circulation remains at about the same level. But should blood be taken directly from the portal vein after a carbohydrate meal, it will be found to contain far more sugar than the blood in the rest of the body. The maintenance of the blood sugar at the same level in the general circulation is due to the capacity of the liver to take up from the portal blood any excess that may be present in it as the result of absorption from the bowel. This excess is stored up within the liver cells in the form of glycogen (a carbohydrate allied to starch). The liver thus acts as a storehouse for carbohydrates, a storehouse from which deficiencies of blood sugar may be made good. This glycogenic function of the liver is under the control of a special centre situated in that part of the brain (the bulb) which supervises so many other bodily functions. Irritation of this centre by puncturing it with a needle leads to an immediate upset in the glycogenic function; it causes a large amount of stored glycogen to be quickly converted into sugar and thrown into the blood stream. As a result there is a steep rise in the blood sugar and a temporary appearance of sugar in the urine (glycosuria). A diabetic condition has been brought about.

The liver plays as important a part in the nitrogenous as in the carbohydrate metabolism of the body. The greater part of the urea and uric acid that are excreted by the kidneys is formed within the liver. Both of these waste materials are by-products of nitrogenous metabolism, and are derived either from the food proteins or else from the breaking-down of body tissues. They are increased therefore on a meat diet or after severe muscular exertions.

The liver is such a highly vascular organ that it can accommodate a large quantity of blood within it. Interposed between the blood vessels which reach it from the alimentary canal (the portal system) and the inferior vena cava, the large vein which empties itself into the heart, the liver can, if

necessary, retain within it enough blood to prevent the risk of over-distension of the heart. This safeguarding of the right side of the heart by the liver is of great importance in certain emergencies, such as those resulting from the existence of heart disease. When the heart shows signs of failing, the liver is generally found to be considerably enlarged, its increased bulk being due to its having retained within it a large amount of blood.

Another service performed by the liver is to remove from circulation damaged and disintegrating red blood corpuscles. The body is run on economical lines, and the precious iron derived from the haemoglobin of these corpuscles is stored within the liver for future use. Whenever there has been a great destruction of red blood corpuscles, as happens in certain cases of anaemia, the presence of considerable quantities of iron can be demonstrated within the liver. It is now generally known that great use is made of liver extracts in the treatment of certain cases of anaemia. This is not because of the iron it contains, but because liver extract exerts a stimulating action on the blood-forming powers of the body. Many cases of anaemia which formerly would have been regarded as incurable are now relieved by giving liver extracts. Although this method of treatment is new to Western science, there are reasons for believing that it has been known and practised by the Chinese for a long time. A lady once informed the writer that many years ago, when she was suffering from grave anaemia and had obtained no relief from Western medicines, she was given some pills by a Chinese. These had a marvellous effect, and upon inquiring what they contained, she was told that they were made from the dried livers of crows. The Chinese explained that he retained the services of a boy to shoot down crows, and that he prepared the pills from their livers.

Since the liver is a very active organ, engaged in a great

number of the body's chemical processes, it is an important means of maintaining body heat. A large part of the warmth of the body is derived either from oxidation processes occurring in the muscles, or else from the chemical activity of the liver.

CHAPTER III

FOOD

IN order that the body may carry on its work and also maintain its structure, it must be supplied with a sufficiency of food. Food has three main functions: (1) it helps to build the body and make good wear and tear; (2) it provides energy for vital functions and daily work; (3) it supplies fuel for heating purposes. If health is to be maintained the food must contain a proper proportion of the various principles entering into a diet, and must be adapted to the age of the individual, to the work that he is called upon to perform, and to the climate in which he lives. Not only must the diet contain a sufficiency of the requisite principles, but they must be present in a digestible form. The ingredients that a diet must contain in order to preserve health are the following:

Proteins	Fats	Vitamins
Carbohydrates	Salts	Water

Proteins are made up of large complex molecules containing the elements carbon, hydrogen, oxygen, nitrogen and generally sulphur. The distinguishing feature of proteins is that they provide the nitrogen (in the form of amino acids) which is essential to the upkeep of body structure. Lean meat, eggs, milk, cheese and such vegetables as peas and beans supply most of our nitrogenous, or body-building, needs. Carbohydrates contain carbon, hydrogen and oxygen, but no nitrogen. The chief carbohydrates in human food are sugar and starch, and these may be regarded as the main energy-producers of the body. Fats, like carbohydrates, contain no nitrogen. Together with carbohydrates they produce energy, and are particularly useful in maintaining the heat of

the body. Chemically they may be split into two constituents, glycerol (allied to glycerine) and fatty acids. We have seen that it is as fatty acids that fats are absorbed from the alimentary canal.

Salts, and more especially the salts of calcium, phosphorus, iron and copper, are necessary for the production of bone, and for the growth and well-being of the body. The main sources of salts are milk, cheese and green vegetables.

Just as we can calculate the amount of fuel required to run an engine, so can we assess the amount of energy-providing food necessary for the vital processes of man. A great deal of research has now been done on this subject, the results of which will be found admirably summarised in a Penguin Special written by Dr. Frank Wokes. This author pointed out that the right use of available food might become a deciding factor in war, and that an inadequate food supply was an important factor in the German defeat of 1918. I am indebted to Dr. Wokes' *Food, the Deciding Factor*, for some of the information contained in the succeeding two paragraphs.

The amount of energy-providing food necessary to a resting man will, of course, depend on his size; for instance, a man of 5 ft. 10 in., weighing 12 stone, will need about 1·79 thousands of calories a day. The energy value of foods is measured in the unit of heat energy, or calorie. A calorie is the amount of heat energy required to raise the temperature of a litre of water one degree centigrade. Given in terms of actual food, a calorie is equal to 4 grains of sugar. Theoretically, therefore, the man described could obtain the energy he needed by consuming a pound of sugar a day, or its equivalent in other forms of food.

If instead of lying in bed the man were to get up and do some work, he would use more energy and require more food. Engaged on an average job his total energy require-

ment would probably be doubled, and he would need about 3·6 thousands of calories a day. Should his work be strenuous his expenditure of energy would probably be in the neighbourhood of 4000 calories a day. Dr. Wokes states that during World War I the energy value of the rations supplied to British, French and German troops was about 4·3 thousands of calories daily.

It may be said that the nutritive value of a diet is determined by the amount of carbon and nitrogen in an easily assimilable form that it contains. This qualification is of great importance; some foods are far more easily digested and absorbed than others; for example, proteins from animal sources are more easily digested than those obtained from vegetables. Digestibility in turn is influenced by the preparation and the cooking of food and by the thoroughness with which it is masticated. The following quantities may be regarded as a suitable diet for a man of average weight performing a moderate amount of muscular work:[1]

	Weight in Grams	Weight in Ounces	Energy Value in Calories
Proteins	100	3.75	400
Fats	100	3.75	900
Carbohydrates	500	18.00	2000

The Vitamins

It is well known that health cannot be maintained on a diet which is merely sufficient to make good the body's output in work and to repair its wear and tear. Sir F. Gowland Hopkins in 1906 found that rats kept on a diet of pure proteins, fats, carbohydrates, salts and water developed signs of malnutrition. His experiments confirmed what had long been suspected, namely, that certain diseases were entirely due to

[1]*Manual of Physiology*, by H. W. Lyle and D. de Souza.

the absence of some essential ingredient in the food. This essential ingredient is now known to be one of those interesting chemical bodies to which has been given the name vitamins. As long ago as 1601 Sir James Lancaster introduced the use of oranges and lemons in the ships of the East India Company in order to combat that old-time scourge of sailors, scurvy. Even then it was recognised that scurvy was the result of an insufficient diet, insufficient as we have since found out because the diet did not contain enough Vitamin C. Another disease that is now known to be due to the absence of an essential vitamin is beri-beri, a disease characterised by weakness, and even complete paralysis, of the legs, associated with dropsy. This deficiency disease is particularly liable to attack communities in which the conditions of living are hard, such as in labour camps and prisons. Between the years 1878 and 1882 from 25 to 40 per cent of the personnel of the Japanese navy was incapacitated by beri-beri. In order to fight the disease Admiral Takaki, director of the medical services, urged a generous increase in vegetables. Fish and meat were also served out to the fleet, and barley added to the sailors' ration of rice.

More recent observations have revealed the existence of many other troubles which are due to deficiencies in diet. Amongst these are rickets, pellagra (characterised by degenerative changes in the skin and mucous membranes), and certain cases of infertility and miscarriage. All these deficiency diseases can be cured by a diet rich in natural foods, such as milk, fruit and vegetables. The precise chemical nature of the vitamins is in process of elucidation. What can be said about them is that, like the enzymes and the internal secretions of the ductless glands, minute quantities have a great effect on the body. The nomenclature of the vitamins is based on their different solubility in fats or in water, and the letters of the alphabet are employed to distinguish them.

The fat-soluble vitamins are A, D and E. Vitamin A is present in large quantities in cod-liver oil, and in smaller amounts in butter and green vegetables. Absence of this vitamin from the diet of young animals results in stunted growth. A deficiency in it also reduces the natural resistance offered by the body to invading organisms. Sometimes a deficiency in vitamin A produces a curious dry condition of the eye known as xerophthalmia. A less severe deficiency impairs the power of vision in a poor light.

Vitamin D, the second fat-soluble vitamin, is also found in cod-liver oil and in lesser amounts in other animal fats, but not in vegetable oils. Its absence from the food interferes with the growth and calcification of bones, and is the cause of rickets. Formerly, when rickets was less well understood, two apparently discordant theories were advanced to explain it. One group of investigators believed that it was purely a diet-deficiency disease. They pointed out that it could be readily cured by adding a small quantity of cod-liver oil to the diet. Another group was equally convinced that the disease was determined by a child's physical environment, for rickets almost always attacked children living in dark industrial cities, and was quickly cured when they were brought into the sunlight. These two apparently contradictory opinions have now been reconciled. Rickets may be caused either by a shortage of vitamin D or else by lack of sunlight. This is due to the fact that the body can obtain its vitamin D by two channels; by the mouth and by the skin. When ultra-violet light from the sun or from an arc lamp strikes the skin it converts a certain fat found there into vitamin D. A child, therefore, can make good any deficiency in his diet by manufacturing his own vitamin, provided that he receives sufficient light. This dependence of a child on sunlight explains also the seasonal incidence of rickets; it is more prevalent during the winter months. Finally, it answers the

(negroes and Italians) were attacked more frequently by rickets than their fair-skinned playmates. This is because pigment in the skin screens off the light that finds its way through the gloom of New York slums. Not only can ultra-violet light enable the skin to manufacture its own vitamin D, but it can increase the efficiency of the various foods that are used in the treatment of rickets. Irradiated cod-liver oil is more potent as a corrective than ordinary cod-liver oil. Vegetable oils, which otherwise have no anti-rachitic action, can be made efficacious by irradiation with ultra-violet light. Finally, rats that have been rendered rickety by a restricted diet can be restored to health by rubbing on their skins irradiated oil.

The third fat-soluble vitamin, E, is also known as the anti-sterility vitamin. Evans and his colleagues, working in the University of California, found that male rats reared on a certain restricted diet became partially sterile in the first generation, and completely sterile in the second. Examination of their reproductive glands showed that these had undergone degeneration. Female rats kept on the same diet also became sterile, but for a different reason. Their ovaries continued to function, but the embryos within their wombs underwent disintegration and reabsorption into the maternal tissues. The diet in some way interfered with the mechanism by means of which the foetus obtained the materials essential to its development. All these changes could be rectified by adding vitamin E to the diet. This, like vitamin D, is found in the majority of common foodstuffs, and more especially in leaves and seedlings. On the assumption that certain cases of human infertility may be due to a dietary deficiency, wheat-germ oil (rich in vitamin E) is sometimes given to childless couples.

The chief water-soluble vitamins are B and C. Absence of

vitamin B is responsible for that strange disease, beri-beri. During the latter half of the last century this disease was a scourge in all rice-eating countries. Gradually it has been realised that beri-beri is due, not to rice itself, but to the eating of rice which has been subjected to milling. Such rice is known as polished rice. If the older methods of separating the husk from the germ were employed, methods that did not remove the pericarp, or nutritive layer, of the rice, beri-beri did not occur. The richest source of vitamin B is yeast, but it is found also in various types of grain. Further examination has shown that vitamin B actually contains as many as six different substances of varying importance. One of these prevents beri-beri, and another pellagra. Pellagra is a tropical disease characterised by severe skin rashes, changes in the mucous membranes, and mental deterioration.

Vitamin C, or the anti-scorbutic vitamin, is present in fresh vegetables, in germinating peas and beans, and in some fruits, especially lemons and oranges. Other vitamins are being discovered, but because less is known about them they will not be described here.

Because rickets and scurvy have become less common in England, and beri-beri and pellagra are non-existent, it must not be assumed that deficiency diseases have been entirely eliminated. Extreme forms of rickets and scurvy may be rare, but there are reasons for believing that lesser degrees of all these deficiency diseases are still prevalent in our midst. Before World War II, Orr made the statement that half of the population lived on a diet that contained insufficient vitamins for the maintenance of health. Much evidence could be brought forward in support of this statement. When in 1928 a random sample of five-year-old children attending L.C.C. schools was examined, 87·5 per cent were found to display some evidence of rickets. From another observer we learn that half of the children at elementary

schools in Cambridge suffered from some deficiency of Vitamin A. It must be realised that science travels far in advance of governments. Although the scientist now knows what food is necessary for health, his advice is seldom asked for, or followed. To the average politician and official the scientist is a theorist and not a practical man. He must be treated with respect, but his advice need be followed only if it falls in line with official views. So we still continue to remove from our wheat the part of it that is rich in vitamins, making good what we have removed by means of vitamins supplied (at considerable expense!) by the dispensing chemist. Not only do we remove from the wheat the pericarp containing the vitamins, but we bleach our flour by means of alkalis that have the effect of destroying the vitamins that have escaped the miller. Having carefully removed all the vitamins it becomes necessary that we should purchase them in tablet form from the chemist. By this compromise with science the interests of the millers are maintained and the prosperity of the purveyors of vitamins is assured.

Essentials of a Diet

Summarising what has been said, it may be stated that if a diet is to be satisfactory it must satisfy the following conditions: it must have a calorific value sufficient to meet the requirements of metabolism; it must contain adequate amounts of protein, fat, carbohydrates, water and salts in suitable proportions; and it must have an ample content of vitamins. Nature has provided for the infant a perfect food in milk. This contains all the necessary food principles in suitable proportions, as well as the more important vitamins. Older children and adults would have to drink inconveniently large quantities of milk in order to obtain a sufficient quantity of certain necessary substances; for example, milk does not contain iron in sufficient quantities for an adult's

needs. Nevertheless, because milk is a body-builder and, through its richness in vitamin A, a disease-preventer, it forms the best single article of food. It is for this reason that at the present time every effort is being made to supply an adequate amount for children and invalids.

A committee of dietetic experts appointed by the Ministry of Health has laid down that the average calorific requirement of a man doing light work is 3000 calories (energy units). A woman occupied in housework needs about 2700 calories, but one engaged on more active work needs as much as the average male. Men occupied in hard work should receive up to 4000 calories, whilst the needs of children are determined by their age. The following diagram (Fig. 9), taken from H. G. Wells' *Science of Life*, shows in graphic form the energy needed every twenty-four hours by men doing different kinds of work:

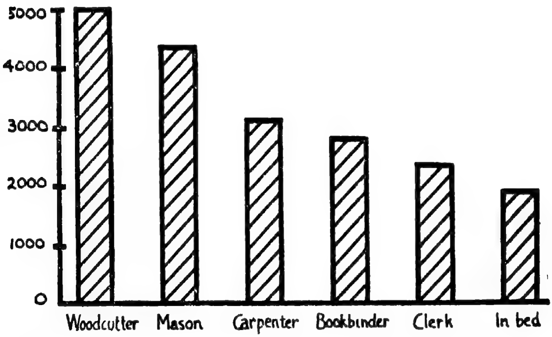


FIG. 9.—Diagram showing energy need (in calories) in 24 hours by men in various occupations. (From *The Science of Life*, by H. G. Wells.)

The constitution of an average normal daily diet has been given by Sampson Wright as follows: protein, 100 grams

(410 calories); fat, 100 grams (930 calories); carbohydrates, 400 grams (1640 calories); total calories equal 2980. It should be realised that a distinction must be drawn between the energy value of the food as purchased and the energy value of the food absorbed after digestion. Not only is some of the energy lost during the preparation and cooking of the food, but a certain percentage escapes digestion and absorption. It is customary, therefore, to deduct 10 per cent from the theoretical caloric value of a diet in order to allow for these losses.

Fortunately uncivilised man has not had to await the investigations of the scientists in order to know the food he requires. Instinctively the Eskimo eats enormous quantities of fat (the best heat-producer) and thus maintains his body temperature. In the same way many individuals find out for themselves that they do better work by increasing their sugar intake. There exist individual peculiarities which necessitate the consumption of more of one kind of food than of another, and frequently a man knows better than his doctor what his body needs. Few generalisations can be made on the subject of diet. It can be stated, however, that there is a tendency among certain types to over-eat. The disadvantages of over-eating are many. It is an economic waste; it puts an unnecessary strain on the organs of digestion, absorption and excretion; it leads to a storing-up of fat that is not only useless, but may be injurious to the body; it may lead to intestinal putrefaction and fermentation, with the resulting poisoning of the system. The excellent results often obtained by nursing homes that specialise in treatment by semi-starvation on small quantities of orange juice are readily explained. After a short course of starvation the putrefaction and fermentation in the bowel ceases, and the patient leaves the home vigorous and refreshed.

Water is the most vital of all the ingredients in man's diet.

But for water life on the planet could not exist. About 60 per cent of the body's weight is due to water. Arthur Shipley in *Life* reminds his readers that 'Even the Archbishop of Canterbury comprises 59 per cent of water'. The precise percentage of water varies in different tissues, ranging from 22 per cent in the bones to 83 per cent in the kidneys. Life without water is as inconceivable as life without air. It is the medium in which vital processes take place, and it is a medium that must be continually replenished. A distinguished scientist, the late Lord Rayleigh (the discoverer of argon), once remarked to the writer that he could not understand why, with so much water already in him, a man should suffer from rheumatism as the result of a slight rise in the humidity of the atmosphere. At the time, Lord Rayleigh was himself returning from a holiday in a drier climate which had been made necessary by a bad attack of rheumatism. No simple or convincing answer could be supplied to his question.

Water is taken into the body not only with our drinks but with practically all the food we swallow. Fresh meat and vegetables contain about 75 per cent of water. Water is eliminated from the body by the lungs, skin, kidneys and bowel. Because water is formed by the oxidation of the hydrogen present in organic foods we excrete slightly more than we take in.

The amount of water present in the body is carefully regulated. Even if we drink to our utmost capacity (more than the total volume of the blood) we are unable appreciably to dilute this fluid. This is because the kidneys keep pace with our intake by means of an increased output of urine. Only when these organs are diseased is there any risk of our becoming water-logged.

CHAPTER IV

THE CIRCULATORY SYSTEM

In the cell and in lower organisms there is no circulatory system, unless we look upon the incessant procession of nutritive granules through the cell substance as a primitive circulation. But a true circulatory system is found in such a low form of life as the round-worms. In mammals the circulatory system is highly developed and of the greatest importance to life. 'The life which is the blood thereof,' states the Bible, and no physiologist will quarrel with this dictum. If the circulation through the brain be stopped only for a few moments, a man loses consciousness. If it be stopped for a longer period, the delicate brain tissue never recovers from the cutting-off of its nourishment. The daily press frequently reports cases in which collapsed patients have been restored to life by massaging the heart. By such bold measures a heart that has stopped beating may sometimes be stimulated into action. Unfortunately, the great majority of those who have been thus revived die twenty-four hours later. Although the rest of the body can tolerate the temporary cessation of circulation, the brain tissue cannot. The smallest change in the composition of the blood immediately reacts on our health and affects even our psychic life. It is with good reason that from the earliest times the heart has been regarded as the most vital organ in the body.

It seems surprising, when we look at it in retrospect, that the discovery of the circulation of the blood was not made long before the time of Harvey. The circulatory system consists of a central pump (the heart) placed in a circuit of closed tubes (the arteries, the veins and the capillaries). What is still

more suggestive is the existence in certain parts of this system of valves so arranged as to allow blood to pass only in one direction. Moreover, it must have been apparent to early observers that the pressure of the blood in the arteries was greater than that of the blood in the veins. As a result blood would be forced in the direction of the lower pressure, that is to say, from the arteries towards the veins. Yet with all this evidence available the medical profession had to wait for the genius of Harvey to discover the circulation of the blood.

The circulatory system consists of the heart, the arteries, arterioles (smaller arteries), capillaries, venules (smaller veins) and veins, in this order. A more detailed examination shows that in most animals there are really two circulations, a greater and a lesser (Fig. 10). The greater system is the circulation throughout the whole body (systemic circulation), and the lesser, the circulation through the lungs (pulmonary circulation). Each has its own heart, but as the two hearts that drive the blood through these two systems are so closely united anatomically we speak of them as one. The right side of the heart is responsible for the lesser, or pulmonary, circulation, and the left for the greater, or systemic, circulation. Because the blood has further to travel in the systemic circulation, and consequently its heart has more work to do, the left side of the heart is stronger and thicker than is the right. Each half of the heart is alike in being composed of two chambers, an auricle and a ventricle. Between these chambers are placed valves which ensure that the blood passes only in one direction, namely, from the auricle to the ventricle. Those on the right side are called the mitral valves because when the two flaps come together they resemble a bishop's mitre. Those interposed between the left auricle and ventricle are called the tricuspid (three-flapped) valves. The flaps of the heart valves are prevented from

bulging too far into the auricles by means of strong fibrous cords. The ends of these cords converge to be attached to

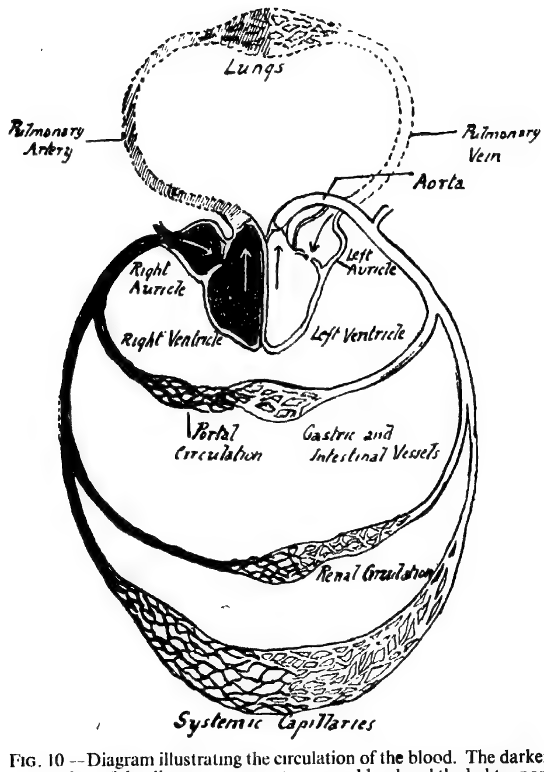


FIG. 10 --Diagram illustrating the circulation of the blood. The darker portion of the diagram represents venous blood and the lighter portion arterial blood. Note that there are actually four circulations: a systemic, a portal, a renal, and a pulmonary circulation.

fleshy columns (papillary muscles) projecting from the ventricular walls (see Fig. 11). The heart valves have very important work to perform and much depends on their efficiency. When any of them become thickened and less flexible through disease, they may no longer act satisfactorily. As a result of this the blood may either be impeded in its passage from auricle to ventricle, or else regurgitate back into the auricle. The patient is then said to suffer from valvular disease of the heart. By listening through a stethoscope the backwash of blood into the auricle may be heard, the sound being described as a 'murmur'. A skilled physician can learn a great deal about the state of the valves and the efficiency of the heart muscles by listening to the heart sounds.

But it is not only between the auricles and the ventricles that we find valves. They are also placed at the origin of the two great arteries (the aorta and the pulmonary arteries) so as to prevent blood flowing back into the ventricles. If the aorta becomes dilated its valves no longer close the opening, and with each beat some of the blood returns into the left ventricle. When this happens the patient is said to be suffering from aortic regurgitation. Since men usually perform more strenuous work than do women, and thus throw a heavier strain on the aorta, aortic regurgitation is essentially a disease of males.

Fortunately the heart is able to a great extent to overcome valvular deficiencies by means of a compensatory thickening of its walls. By working harder and forcing more blood onwards, the regurgitation, whether it be back into the auricle or into the ventricle, is neutralised. In such a case valvular disease is said to be fully compensated, and the patient is able to live a more or less active life. It is only when compensation is unsatisfactory that grave symptoms are likely to arise. This happens when the heart begins to dilate,

its reserve power having been expended. Then the patient becomes breathless and is unable to make any exertion.

The circulation will best be understood by following the course of the blood from the left auricle onwards (see Fig. 10). Starting at this point, blood is forced by the thick-walled ventricle into the aorta. This is by far the largest of the blood

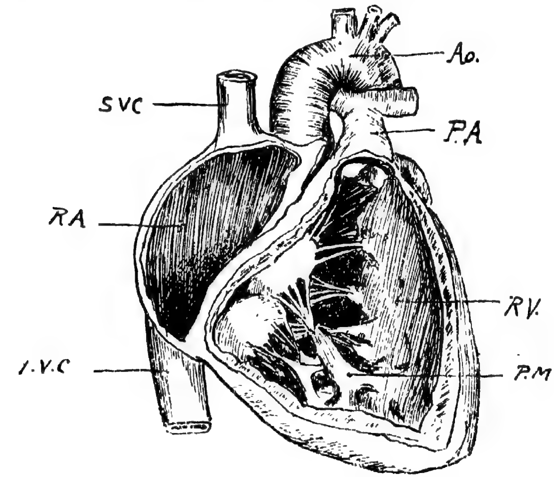


FIG. 11.—The human heart. *R.A.*, right auricle. *R.V.*, right ventricle, showing tricuspid valve and *P.M*, papillary muscles into which the cords of these valves are inserted. *Ao*, aorta. *P.A*, pulmonary artery. *S.V.C.*, superior vena cava. *I.V.C.*, inferior vena cava. (After Allen Thompson.)

vessels, since it is the channel through which blood reaches all the arteries of the body with the exception of those which supply the lungs. The big branches of the aorta break up into smaller and yet smaller arteries and arterioles. If traced onwards it will be seen that these finally lose themselves in a

PLATE 1

The stomach and duodenum are outlined by bismuth. This has also passed into the jejunum, the upper part of which is less clearly defined. The constriction in the stomach has been caused by a wave of peristalsis travelling along its muscular coats.

delicate network of capillaries, so small as to be invisible to the naked eye. The capillaries eventually run into tiny veins, which joining up together become bigger, until they unite to form the inferior and superior venae cavae. These great veins pour their contents into the right auricle. During its course through the body the blood has given up much of its oxygen, and, in return, it has received much of the waste products of the body. Having started from the left auricle as pure arterial blood, it returns to the right auricle as impure venous blood. Before it can be of any further use to the body it must be re-oxygenated and must get rid of some of the carbon dioxide that it has accumulated. This cleansing process is brought about by its passage through the lungs. We will continue to follow its course through the pulmonary system. From the right auricle the blood passes into the right ventricle and thence by the pulmonary arteries to the lungs. As in the systemic system, the larger vessels break up into smaller vessels and eventually into capillaries. It is in these pulmonary capillaries that the blood is purified and re-oxygenated. It then returns by the pulmonary veins to the left auricle, thus having completed an entire circuit of two systems, the systemic and the pulmonary.

Fig. 10 shows diagrammatically the course taken by the blood in making a complete circuit. The diagram shows also two additional systems of circulation, the portal and the renal. These subsidiary circulations are concerned with absorption and excretion respectively. In Chapter II it was stated that certain products of digestion, namely, sugars and broken-up proteins, passed into the network of the capillaries in the intestinal villi. The blood in the capillaries of these villi eventually reaches veins which unite to form the portal vein. This great channel passes to the liver, and there again breaks up into capillaries within its substance. The liver therefore, like the lungs, has a special circulation. It receives

all the blood from the intestinal walls, blood that is rich in foodstuff. From the liver capillaries the blood travels to the inferior vena cava, and thence to the right auricle.

The renal circulation is very similar to that of the liver, but the blood flowing through the kidneys is rich in waste products instead of being rich in nutriment. It is the work of the kidneys to remove these, as it is the work of the lungs to get rid of carbon dioxide. The subject of the renal circulation will be dealt with more fully in Chapter VI.

Having studied the circulation it is now necessary to consider the working of the heart. The muscular fibres of which the walls of the heart are composed are somewhat different from those in the muscles. They are shorter and less striated, and also are in a different relationship to the central nervous system. The relation between the muscles that move the body and the central nervous system is so intimate that if the nerves running to a muscle are cut, that muscle is no longer able to contract unless it be stimulated by an electric current. The muscles of the heart are much more independent of the central nervous system. If the heart be removed from a frog it will go on beating for hours, even though all its nerves have been severed. We may say, therefore, that the heart's action is automatic, meaning by this that it is not dependent upon impulses carried to it by nerves. If we watch carefully the beating of an excised frog's heart, we will note that from time to time a wave of contraction passes over it. This starts in the great veins, spreading to the auricles, then to the ventricles and finally to the great blood vessels springing from these cavities. What causes the muscles of the heart to be thrown into these contractions is not very clear, but it is possible that the inner stimulus is a chemical one. A certain investigator has stated that he has discovered a heart hormone, or chemical messenger. By extracting this from the heart wall he has been able to re-start the beat of another

heart which had been quiescent for three and a half days. However, what is important to remember is that the heart-beat is not initiated by any nervous stimulus.

If we watch very carefully the beating of an excised heart we shall note a slight delay in the passage of the waves of contraction from the auricles to the ventricles. In order to reach the ventricle the contraction has to pass along a special bundle of muscle fibres known as the auriculo-ventricular bundle. In certain pathological conditions the conductivity of this bundle is impaired, and the ventricle beats less frequently than the auricle. This condition is generally referred to as one of heart-block. When digitalis is given by a physician to slow down the heart, this drug probably acts by reducing the conductivity of the auriculo-ventricular bundle, thereby lessening the number of impulses reaching the ventricle from the auricle. The action protects the ventricle from over-frequent and inefficient beating, thus giving it an opportunity for rest. The heart, like other muscles, must be supplied with nourishment from which to obtain energy. Experiment has shown that it is much in need of inorganic salts. If a strip of a turtle's heart be immersed in saline it continues beating for a time and then the beats become feebler and feebler. If we now add to the saline some calcium and potassium chloride the heart revives and again contracts forcibly.

Although the heart beats automatically, like other organs in the body, it receives nerves from the central nervous system. Stimulation of one set of nerve fibres running to the heart (the vagus) causes a slowing of the beat, and of another set (sympathetic nerve) an acceleration of the heart. The accelerating nerves come into action in a state of fear and prepare the body for fight or flight. By the increased frequency of the heart-beat more blood is supplied to the muscles, thus rendering them capable of greater exertion.

When blood is pumped from the ventricle into the aorta, the valves in the latter prevent any backward flow. With each beat of the heart the walls of the aorta expand. Since the arteries are elastic, the successive jerks by which the blood is pumped into them are converted into a more continuous and even flow. But the intermittent impulse given to the blood in the aorta is never entirely lost in the arteries, for when an artery is severed blood escapes from it in a series of spurts. This spurting distinguishes arterial from venous bleeding, in which the flow is continuous and at a much lower pressure. The expansion of the walls of the aorta caused by more blood being forced into it is propagated as a wave along the whole course of the arteries. This wave of expansion can conveniently be felt in the radial artery at the wrist and is known as the pulse. In feeling the pulse a doctor notes the following points: its frequency (about 72 beats per minute), its force (indicating the strength of the contraction of the left ventricle), its regularity (an irregular pulse indicates an irregular heart rhythm), the equality of the beats, and the tension of the pulse. By tension is meant the amount of force required by the palpating finger to obliterate the pulse wave. Finally, by palpating the radial artery a doctor can learn much about the condition of its walls, whether they be soft and elastic, or thickened and hard.

The arteries, like the heart, are under the control of the central nervous system. Like it also, the nerves supplying the arteries are of two kinds. Stimulation of one set of nerves reduces the calibre of the artery by causing its walls to contract, and stimulation of the other set increases it by causing them to dilate. In other words, the two sets of fibres bring about vaso-constriction and vaso-dilatation respectively. Fear causes not only an increased frequency of heart-beat, but also a constriction of the arteries, as is shown by the blanching of the skin of a frightened person. The opposite

condition of vaso-dilatation is produced by the psychic state of shame and shyness, and is known as blushing. By means of these two opposing sets of fibres the supply of blood to the various organs of the body is regulated in accordance with their needs, an increase in the activity of the organ being associated with vaso-dilatation, and a diminution in it with vaso-constriction.

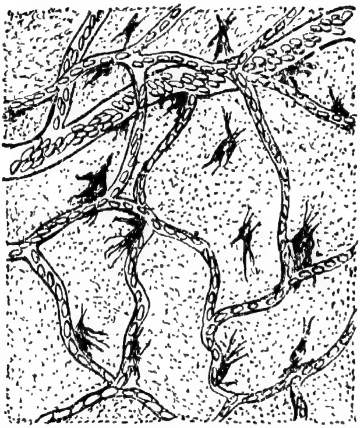


FIG. 12.—Capillary circulation in the foot of a frog. The dark cells are pigment cells

The purpose of the circulation is to bring to the tissues the substances necessary for their nutrition, and to remove from them the products of their katabolism. This interchange of material can take place only in the network of fine thin-walled capillaries. These blood channels eventually become so minute that only a single file of blood corpuscles can proceed along them (see Fig. 12). Formerly it was believed that the capillaries were purely passive conduits, but they are

now shown to be contractile. This being so, their capacity can be varied according to the requirements of the tissues which surround them. The ability of the capillaries to contract or dilate may be demonstrated by the simple experiment of drawing the finger sharply across a person's bare back. The first result of this action will be to cause a white line (vaso-constriction). For the white line is quickly substituted a red streak (vaso-dilatation). The readiness with which these streaks are produced varies in different individuals and in different psychic states. In certain neurotic conditions the weals appear with great rapidity and intensity.

From the capillaries the blood passes into tiny veins and eventually, like a river that has received innumerable tributaries, reaches the larger veins of the body. The onward flow of the blood in the veins is assisted by the massaging effect produced by the contraction of the muscles of the body. It is also aided by a suction action from in front, caused by the movements of the chest. During inspiration the increased negative pressure within the chest expands the large veins that empty their blood into the auricles and draws the blood onwards towards the heart. These aids to the flow of blood within the veins can be effective only if all backwash be prevented. This is ensured by the existence of valves within the veins.

The velocity at which the blood flows varies in different parts of its course; in the aorta it travels at the rate of one-half metre per second, in the capillaries at that of half a millimetre per second, and in the veins at a third of the rate at which it flows in the arteries. The shortest time taken for blood to make a complete circuit of the body has been determined by injecting a chemical into the central end of a severed jugular vein, and then noting the interval required for its appearance at the other end. As a result of this experiment it has been found that the shortest time required for a

complete circulation corresponds to twenty-seven beats of the heart, less than half a minute.

The distribution of the blood in the body is influenced by such factors as gravity and activity. A moment's reflection will show that the position of the body must have some effect on circulation. When the hand is raised high above the head the skin of the hand becomes paler and the veins less obvious. When it is allowed to hang down, the skin recovers its colour and the veins fill out. If a hutch rabbit is suspended by the ears it soon becomes unconscious, owing to the fact that the blood drains away into the large veins of the abdomen and the brain is deprived of its nourishment. Should the same experiment be repeated with a wild rabbit, it will be found to tolerate suspension by its ears much better than does the hutch-reared animal. This is because the tone of its blood vessels is superior; it has the power to contract the walls of the abdominal veins and thus prevent all the blood from draining into them.

This subject of the action of gravity on the circulation is of some importance in connection with the development of varicose veins. The veins that are most likely to be affected with varicosity are the dependent veins of the legs. The condition is found most frequently in people who are compelled to stand a great deal, such as domestic servants, shop assistants and cooks. Those who walk rather than stand are less liable to this trouble, because the flow of blood through their legs is assisted by the massaging action of their muscles. Sedentary occupations may lead to a similar congestion of the veins of the liver and of the intestines, the sedentary worker resembling the tame, rather than the wild, rabbit. It must be remembered that every activity of the body has some influence on the distribution of blood. By suitable instruments it may be shown that the solving of an arithmetical problem may cause the volume of the arm to diminish, blood

being drawn from the rest of the body in order to meet the increased demands of the brain. For a similar reason a heavy meal generally leads to mental apathy. In this case the blood has been drawn into the abdomen to assist digestion at the expense of the brain. Blood is also withdrawn from the skin for the same reason, and this explains why many people feel cold after eating. Constriction of the skin blood vessels is associated with a feeling of coldness.

It is well known that when anyone feels faint his head should be kept low, so that the brain shall not be deprived of nourishment. In the majority of cases this is automatically ensured by the patient falling to the ground. The worst service that an onlooker can offer in such circumstances is to attempt to raise the patient to his feet and thereby deprive the brain of the blood it so badly needs. For the same reason the foot end of the bed is raised when a patient is suffering from severe shock, or from having lost a great deal of blood. In such circumstances the blood pressure is always below normal, and in order to raise it fluids (salines, serum or blood) are injected into the patient's veins. The normal pressure in the artery of the arm is equivalent to 110 millimetres of mercury. It is increased by exercise, and falls again with rest. An abnormally high pressure is sometimes indicative of heart disease, but it is more often the result of thickening and hardening of the arteries.

The Nature of Blood

The blood is the fluid medium that carries nutriment to the body and collects from it the waste products of its metabolism. It carries oxygen from the lungs to the tissues and receives in exchange carbon dioxide. It is also the means by which heat formed in the tissues is distributed to all parts of the body, so that a uniform temperature is maintained. The internal secretions of the ductless glands are distributed by

the blood stream. Finally, the blood takes a large part in the defence of the body against bacterial invasions.

The total amount of blood in the body is, roughly, one-thirteenth of the body weight. With all the varied work it has to perform it is not surprising that on examination the blood proves to be a very complex fluid, its exact composition varying slightly in different parts of the body. By means of a centrifuge blood can be separated into two parts, a liquid and a solid, the liquid being the serum and the solid the corpuscles. We shall first study the solid constituents of the blood.

Blood Corpuscles

Corpuscles are of two kinds, red and white. A microscopic examination of human red blood corpuscles shows that they are bi-concave, circular disks, $\frac{1}{3200}$ of an inch in diameter (see Fig. 13) Because of the similarity in their shape and size it is impossible under the microscope to distinguish between the corpuscles of different mammals, including man. Unlike other cells in the body the red blood corpuscles of most animals do not contain a nucleus, except when they are very young. The corpuscles of amphibians (for example, the frog) are peculiar in that they are nucleated, and therefore readily distinguishable from those of a mammal. By counting the number of corpuscles in a film of blood of known thickness their number can be estimated. This method of examination is employed in the diagnosis of anaemia. In a healthy subject there are about five million red cells in every cubic centimetre of blood, but in anaemia the number may fall as low as a million. Structurally the red blood corpuscles are made up of a framework the protoplasm of which holds in its meshes a

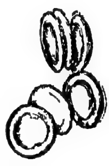


FIG 13.—Red blood corpuscles.

complicated red pigment known as haemoglobin. This pigment contains a large amount of iron, and has the special characteristic of being able to unite with oxygen so as to form a new compound, called oxy-haemoglobin. Not only does haemoglobin combine easily with oxygen, but it parts with it equally readily. All that it is necessary to do in order to form oxy-haemoglobin is to bring oxygen into contact with haemoglobin, and all that need be done to break it up again is to reduce the pressure of oxygen in the surrounding atmosphere. These two processes occur in the body; in the lungs, haemoglobin is converted into oxy-haemoglobin, and in the tissues, back again into haemoglobin. Oxygen is, however, not the only gas with which haemoglobin forms a loose compound. It also has the power of uniting and parting with carbon dioxide, and it is this faculty that enables the blood to absorb carbon dioxide from the tissues and to give it off in the lungs. Unfortunately haemoglobin combines with carbon monoxide, the toxic ingredient of coal gas, forming a more stable compound. This accounts for the many deaths that are caused by inhaling coal gas. Nitrous oxide, or laughing gas, does not unite with any part of the blood, or interfere with its oxygen-carrying properties. For this reason nitrous oxide is a very valuable and safe anaesthetic.

The white corpuscles of the blood are much less numerous than are the red. In health the proportion of leucocytes (white blood corpuscles) to red corpuscles is about 1 to 500. In inflammatory diseases the leucocytes are considerably increased. They are the warrior cells of the body and they must be quickly mobilised if they are to succeed in repelling the invading micro-organisms. They are slightly larger than the red corpuscles, and, like the vast majority of cells in the body, they are nucleated. Four or five different varieties of leucocytes can be identified, according to their size, the shape of their nucleus, and the character of the granules scattered

throughout their substance. Each type of leucocyte probably has a different work to perform in combating a bacterial invasion. One type is believed to have the power of diffusing into the blood-plasma substances that have a destructive action upon the invading bacteria, and another of being able to fix, or render harmless, the poison secreted by the enemy. A third variety, known as phagocytes, can engulf the dead bacteria when they have been rendered harmless by the action of the other leucocytes. A battle between the invading organisms and leucocytes can be watched under the microscope. It is a dramatic spectacle. But battles cannot be won without casualties and the killed amongst the leucocytes take the form of 'matter', or pus. When the invasion is a serious one the turmoil of the conflict affects the whole body. The patient suffers from a raised temperature, increased action of the heart and such symptoms as poisoning, headache, malaise, loss of appetite and pain. His whole system may be flooded with toxins, affecting not only his body but also his mind. In extreme cases he will be delirious, suffer from hallucinations and lose all contact with reality. When the battle goes in his favour it may only be at the cost of a vast number of dead leucocytes. An abscess may form and the dead bodies of the defenders will have to be evacuated as pus. But better an abscess than death from blood poisoning.

Sometimes, as the result of a victory over invading organisms, the blood becomes endowed with properties that render the body permanently immune to further attacks from that particular enemy. Thus a patient who has recovered from smallpox will never again be susceptible to smallpox infection. This is due to the presence in the patient's blood of what are known as 'immune bodies', or substances which can neutralise bacterial toxins. These often remain in the blood for the rest of the patient's life. Use is made of this immunity principle in the serum treatment of disease. To

prepare serum, blood is drawn off from an animal that has previously dealt successfully with the disease in question, and allowed to clot. The serum (containing the immune bodies) separating from the clot is then injected into another animal that is at that moment being attacked by the disease. Immune serum of this kind is given in order to neutralise the poison that is poured into the blood during an attack of diphtheria or of tetanus (lockjaw). This method of treatment by means of immune sera is quite different from treatment with vaccines. In the latter case the aim is to mobilise quickly the resisting power of the patient's own blood. This is done by injecting into the patient either the dead bodies or weak strains of the organism against which protection is desired. As a result he actually suffers from a mild form of the disease and thus gains an immunity to it. Inoculation with typhoid vaccine practically eliminated this disease amongst troops serving in France during World War I. The difference between the two forms of treatment is that when serum is used the patient borrows resistance from another organism, and when vaccines are used he is helped to mobilise his own resources. These two methods of treatment are known as serum-therapy and vaccine-therapy respectively.

Since the number of red corpuscles in the blood stream remains fairly constant even though they are being continually destroyed, it is obvious that they must be replenished from time to time. New blood corpuscles are formed in the red marrow of the bone from large colourless nucleated cells found in this situation and known as erythroblasts. The cells destined to be red corpuscles acquire haemoglobin and eventually lose their nuclei. Whenever there is a sudden demand for fresh blood, as after a severe haemorrhage, the bone marrow becomes very active. High altitudes have the same effect of stimulating the formation of new blood corpuscles as does haemorrhage. Because of the low atmospheric

pressure obtaining there, the presence of a surplus number of oxygen carriers in the blood becomes necessary. Old and worn-out red blood corpuscles are deposited in the spleen and liver. Both of these organs store iron derived from disintegrated haemoglobin, iron that is eventually used again in the manufacture of fresh haemoglobin.

The phenomenon of clotting is of great importance to the body. If it were not for the fact that blood coagulates after leaving the blood vessels, the slightest injury of a blood vessel might have a fatal result. In a few people suffering from the hereditary disease known as haemophilia, the clotting power of the blood is deficient, and victims of this trouble are in danger of bleeding to death whenever a blood vessel is injured. Two of the royal families of Europe suffer from this disease. One of its characteristics is that it only affects males, although only females can transmit it to their offspring.

Three stages may be noted in clotting: first the blood becomes viscous, then gelatinous, and finally a straw-coloured serum is squeezed out from the clot that has been formed. After a few hours the shrunken clot floats on the surface of the serum.

Actually, coagulation is a very complicated process dependent on the existence in the blood of an enzyme which is brought into action by calcium. For many hundreds of years attempts have been made to make good loss sustained in haemorrhage by means of infusions of blood, but all attempts were formerly frustrated by the rapidity with which the donor's blood clotted. In the Middle Ages efforts were made to revive Pope Innocent VIII by transfusing him with the blood of two boys. Not only did the pope die, but also the two donors. Sir Christopher Wren was so interested in blood transfusion that he designed a special chair to facilitate the process. But it was only when the clotting difficulty

was overcome by the use of potassium citrate that transfusion became a practical measure. Now it is one of the most valuable remedies that medicine possesses. Great improvements in the technique of blood transfusion were made during World War I. It was probably the only advance achieved by medicine during those disastrous years.

The Circulation of Lymph

So far we have described the circulation only of the blood. We must now turn to the circulation of lymph through the body. Many of the blood capillaries are so minute that the red cells can pass along them only in single files. Because their walls are exceedingly thin they are permeable to water, salts and gases. Consequently fluid is continually passing through the walls of the fine capillaries into the surrounding spaces, and this fluid is called lymph. The spaces in which this exuded fluid collects vary much in shape and size. They sometimes widen into large expanses which are known as serous cavities. It is from the lymph rather than from the blood that the tissues receive their nourishment and into it that they excrete their waste products. The lymphatic spaces found in the tissues end in a series of delicate tubes called the lympathic capillaries. These, like the blood capillaries, eventually pass into larger lymph vessels, which, like the veins, are fitted with valves. The lymph vessels from the lower limbs, as well as those from the abdominal organs, unite to form the largest lymph vessel in the body, called the thoracic duct. This, after being joined by the lymphatics of the left arm and of the left side of the head, neck and chest, empties its contents into the left subclavian vein. Lymph from the right side drains into the right subclavian vein.

The flow of lymph is very slow compared with that of the blood stream. As in the case of the veins, the flow along the lymphatics is assisted by the massaging action of the muscles,

and also by the movement of the chest wall. Part of the benefit derived from Swedish massage comes from its action in speeding up the lymph flow. The increased flow of lymph ensures that the area under treatment receives plenty of nutriment and gets rid of its waste products promptly. All the natural processes of repair are thereby encouraged.

In the course of the lymph vessels are placed at frequent intervals small oval masses, known as the lymphatic glands. They act as filters, removing from the lymph some of its impurities, such as bacteria. The lymphatic glands which are best known to everybody are those of the neck. Since it is the work of these glands to filter off organisms that have gained an entrance to the body through the tonsils, the nose, the throat and the teeth, they frequently become inflamed. Sometimes the organisms that have been trapped by the gland are so virulent as to cause abscesses, especially if they happen to be tubercle bacilli. It should be noted that there is no relationship between these lymphatic nodules which form a part of the lymph system and secreting glands. The use of the word gland for both structures is apt to cause confusion.

It will be seen that in dealing with the circulation in the body we have had to describe not one but several circulations. There is the circulation of the lymph as well as the circulation of the blood. Even when we limit ourselves to the blood we find that there are several circulations to be considered, the systemic, the pulmonary, the portal and the renal. But varied though they may be, these circulations, whether of blood or of lymph, all have the same function, namely, that of carrying nutriment to where it is needed most and removing from the tissues the waste products of their metabolism.

CHAPTER V

RESPIRATION

In Chapter II we studied the means by which the body obtained the raw material necessary for the maintenance of its structure and for the work it is called upon to perform. The absorption of nutritive material from the alimentary canal was described, and some indication given of the nature of body metabolism. In these metabolic processes oxidation plays a large part. It will now be necessary to study the means by which the body obtains the considerable amount of oxygen that it requires for its purposes. Methods that are sufficient for the oxygen needs of lower organisms are insufficient for the needs of man. Absorption through the skin would provide only a small fraction of the oxygen that is demanded by man's vital chemistry. Only by a special apparatus can he obtain all the oxygen that he requires, and get rid of the carbon dioxide that has accumulated in his blood. This special apparatus for providing oxygen is the respiratory tract.

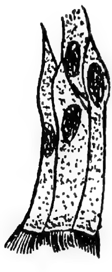


FIG. 14.
Ciliated cells.

The respiratory tract includes the nose and naso-pharynx, the larynx, the trachea, the bronchi and the lungs. Like the alimentary canal, the respiratory tract is lined with mucous membrane, but of a different nature to that which is found in the digestive system. The mucous membrane of the respiratory tract contains certain cells called goblet cells, which form mucus, and others fringed with cilia, or hair-like processes, which move only in one direction (see Fig. 14). The mucus secreted

by the goblet cells keeps the surface of the trachea and bronchi moist, and also serves to entangle particles of dirt which have entered the respiratory tract during inspiration. These particles, having been caught, are swept upwards towards the mouth by the ceaseless movement of the ciliated cells. These act like a number of minute brooms which keep the respiratory tract clean. Should the mass of foreign matter that has got into the respiratory tract be greater than the ciliated cells are capable of dealing with, another mechanism is called into action, namely, the mechanism of coughing. Coughing is an example of the many protective reflex mechanisms with which the body is supplied. It is the means by which we get rid of foreign matter, whether it be dust, mucus or pus, which is irritating our respiratory passages. Because it serves a useful purpose, the last thing that a physician wants to do is to arrest the cough of a bronchitic patient whose respiratory passages are clogged with mucus and pus.

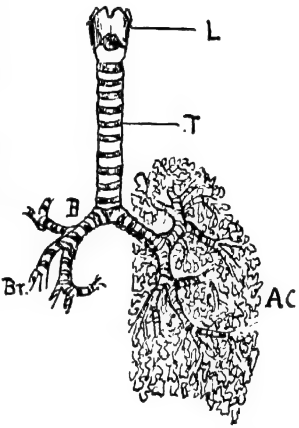


FIG. 15.—Respiratory system. L., larynx T., trachea. B., main bronchi. Br., bronchiole. A C., air cells Note the rings of cartilage surrounding the trachea and bronchi.

The trachea, the main passage into the lungs, is about four and a half inches long. It begins with the glottis and ends in the upper part of the chest, where it divides into the right and

left bronchi. Each bronchus gives rise to smaller branches, which eventually break up into bronchioles. The bronchioles terminate in the tiny air cells, or infundibula, of the lungs (see Fig. 15). The bronchi and bronchioles may be looked upon as being continuations of the trachea, and, like it, they are held permanently open by a series of rings of cartilage. The whole of the respiratory tract can be pictured as an inverted tree, the trachea constituting the trunk, and the bronchi its first division into large branches. From these main branches arise smaller branches, or bronchioles. The ultimate division is into air cells, which, budding from the bronchioles, may be likened to the leaves of the tree. The parallel between the air cells and the leaves is indeed a close one. It is by its leaves that a tree breathes, and it is by its air cells that an animal takes up oxygen and gives off carbon dioxide. As the branches of the pulmonary system get smaller and smaller their walls become correspondingly simpler and thinner, until finally they are so delicate as to consist only of a single layer of flattened cells held together by a minimum of connective tissue. Closely applied to the outer surface of these thin walls is a dense network of capillaries which brings the impure blood to the lungs (see Fig. 16). The thinness of the walls of the air cells serves a definite purpose; it allows carbon dioxide to pass from the blood into the cavity of the air cell, and oxygen to pass in the opposite direction. Since the total expanse of lung epithelium is enormous, a sufficient interchange of gases takes place, within a very short time, to convert all the venous blood of the body into arterial blood. It has been estimated that if all the lung epithelium of an adult man could be spread out flat, it would cover about a hundred square yards. This statement sounds incredible until we remember that the walls of the lung alveoli are of superlative thinness, thinner than the finest gold leaf that man has ever succeeded in making. Purified and oxygenated, the

blood from the air cells is collected up into venules and returned to the left side of the heart by the pulmonary veins. It should be noted that, contrary to what happens in other circulations, it is the pulmonary artery that conveys the impure blood, and the pulmonary vein that carries pure blood back to the heart.

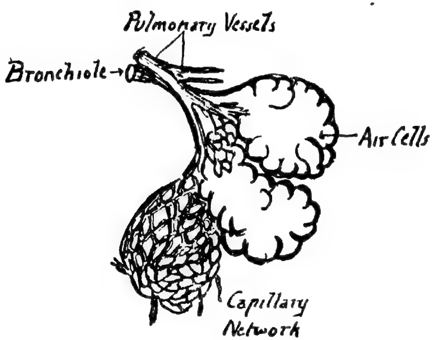


FIG. 16. – Three air cells of the lung The lowermost shows the network of capillaries with which the air cell is surrounded.

Each lung, divided into several lobes, is surrounded by a double layer of smooth shining membrane which is called the pleura. That part of the membrane which is adherent to the lung is known as the visceral pleura, and that part which lines the inner surface of the chest wall, as the parietal pleura. The smoothness of these two linings allows the lung to slip over the inner surface of the chest during breathing, with the minimum of friction. When the pleura is inflamed, when, in other words, the patient suffers from pleurisy, the movement of one layer of the pleura over the other becomes difficult and painful, and the patient complains of distress whenever

he takes a breath. In many cases of pleurisy inflammatory fluid is formed between the two layers of pleura, collecting in the space that separates the lung from the wall of the chest. If this fluid should turn purulent the patient develops what is called an empyema, and the pus must then be evacuated by an incision into the chest wall. It will be remembered that this operation had to be performed on King George V during his last illness.

The Mechanics of Respiration

The lungs enclosed in their pleura are suspended in an air-tight box, the thoracic cavity. The walls of this box (formed by the ribs, the sternum, the vertebral column and the diaphragm) are movable and therefore its capacity may be either increased or diminished. With an increase in the size of the chest, the lungs expand so as to fill the new space which has been created, and with a diminution they contract. If the lungs did not expand with each increase in the size of the chest, a vacuum would be created between them and the chest wall. The capacity of the chest is increased during inspiration by two mechanical actions, an upward movement of the ribs and a downward movement of the diaphragm. The latter is a strong, muscular, dome-shaped partition which separates the chest from the abdomen. When the diaphragm contracts the dome is flattened out. Since the ribs are placed obliquely, sloping downwards and forwards from the vertebral column to the sternum (breast bone), it is obvious that when they are raised the capacity of the chest will be increased. This raising of the ribs is accomplished by the muscles of the chest wall, and is synchronised with the downward pull of the diaphragm. The forcible descent of this dome of the diaphragm increases the pressure within the abdomen, with the result that the abdominal wall is pushed forward. All these co-ordinated movements of chest and dia-

phragm, together with the drawing of air into the lungs, constitute the act of inspiration.

Expiration, brought about by a diminution of the capacity of the chest, may be either active or passive. In ordinary quiet breathing no muscular action is needed to bring back the chest wall to its resting position. The natural elasticity of the tissues and the weight of the chest are sufficient for this purpose. But during forced, or laboured, breathing additional help is afforded to expiration by the muscles of the abdominal wall. By contracting, these muscles increase the intra-abdominal pressure and force back the diaphragm towards the chest. The part played in breathing by the chest wall and the diaphragm differs in different individuals. As a general rule women are more dependent on chest breathing and men make relatively more use of the diaphragm.

When respiratory movements have ceased, as in an apparently drowned person, or in a patient who has collapsed under an anaesthetic, they must be artificially imparted to the chest wall until automatic breathing is resumed. The technique of artificial respiration now generally favoured is that described by Schafer. To carry this out the patient is placed face downward, with a cushion, or folded coat, under the lower part of the chest. After ensuring that the upper part of the respiratory passages is free from any such obstruction as mud, weeds, etc., the resuscitator kneels on the ground, either athwart or at the side of the patient, facing his head. The hands are then placed flat over the lower ribs, one on each side of the vertebral column. The chest can be compressed by throwing the weight of the body forward on to the hands, and then allowed to expand by raising the body slowly to the upright position, leaving the hands still on the chest. This forward and backward rocking movement is repeated every four or five seconds so as to initiate respiration. It must be persisted in for at least half an hour,

and in some cases even for an hour, or until natural respirations are resumed. Once breathing has been re-established the patient may be turned over on to his back and his circulation assisted by massaging the limbs in the direction of the heart, and by applying hot flannels, hot-water bottles, etc. As soon as he can swallow, small quantities of warm drinks should be given.

The expansion and contraction of the lungs with the movement of the chest wall is entirely dependent on the fact that they are suspended in an air-tight box. If a hole were to be made in the chest wall and air admitted, the lungs would immediately collapse. Advantage is taken of this fact in the modern treatment of phthisis. In order to put a diseased lung at rest and thus give it a chance of recovering, air is deliberately admitted into one side of the chest, thus creating what is known as an artificial pneumo-thorax (from two Greek words meaning air and chest). In time the air introduced into the chest is absorbed, and if a prolonged rest is necessary the process will have to be repeated.

Although the movements of the lungs are entirely passive, that is to say, imparted to them by the movements of the chest wall, the respiratory tract contains a small amount of muscular tissue. The bronchi and bronchioles are surrounded by a thin layer of muscle, which, when it contracts, diminishes their lumen. Spasm of these muscle fibres is responsible for that distressing condition, asthma. The cause of the spasm varies in different individuals, but generally speaking, asthma runs in families and is a trouble from which nervous and anxious people are liable to suffer. It has many features in common with hay fever, and, like it, may be provoked by a number of widely differing stimuli, such as irritation from pollen, feathers, etc. The remedies that are administered are designed to relax the muscles in the bronchioles and to make breathing easier.

Having studied respiration, it is now possible to consider the different conditions that may affect it, such as exercise and alterations in atmospheric pressure. It is obvious that prolonged muscular exercise, such as that entailed by running, causes dyspnoea, or breathlessness. When muscles contract, oxygen is used up and carbon dioxide given off. This throws more work on the lungs, and in order to increase the intake of oxygen and the expiration of carbon dioxide respiration becomes more rapid. The increased frequency of breathing is an automatic action brought about through the central nervous system. In the part of the brain that is continuous with the spinal cord (the bulb) is situated a respiratory centre. The increased amount of carbon dioxide circulating in the blood acts upon this sensitive centre and causes a quickening and deepening of breathing. The quickened respiration is the result of a chemical stimulus (excess of carbon dioxide in the blood) applied to a nervous mechanism (the respiratory centre in the bulb). Quickened breathing, in turn, brings about a fall in the carbon dioxide in the blood, and thus removes the stimulus acting on the respiratory centre.

Mountain climbers and airmen are compelled to breathe more deeply and more frequently for a different reason. The diminished oxygen pressure at high altitudes results in a poor oxygenation of the blood. As a result they are liable to dyspnoea (breathlessness). It is well known that those who live habitually at a great height, such as the inhabitants of some towns in the Andes, become accustomed to breathing in a rarefied atmosphere. This is because another compensatory mechanism has had time to come into action; the red corpuscles in their blood increase in number, so that they can carry a greater quantity of oxygen. But those who are suddenly exposed to a diminished pressure are unable to adjust themselves to the new conditions. They suffer from

breathlessness, insomnia, inability to make any exertion and sometimes vomiting. All these unpleasant symptoms can be relieved by inhaling oxygen. Consequently, an apparatus for giving oxygen is an essential part of the equipment of Mount Everest climbers and high-altitude flyers.

The ill effects resulting from the converse condition, namely, breathing in an increased atmospheric pressure, are quite different from the above. For a long time it has been known that divers and workers in caissons (steel chambers sunk in water and filled with compressed air) are subject to certain symptoms on returning to the surface. When mild these symptoms take the form of pains in the joints, and because these pains compel workers to flex their joints, the discomfort is commonly known as 'the bends'. In severe cases of caisson disease there may be complete paralysis ending in death. This is because under high pressure the air (consisting of oxygen and nitrogen) is taken up in solution by the body tissues. When the pressure is reduced the dissolved gases are given off again into the tissues as bubbles of oxygen and nitrogen. These tiny air bubbles block the circulation and may put the central nervous system out of action. To prevent this happening the high pressure to which the workers have been exposed during work must be reduced very gradually so as to enable the dissolved oxygen and nitrogen to be liberated more slowly.

In addition to giving off carbon dioxide the lungs also eliminate from the body a large quantity of water vapour. This is easily demonstrated by breathing on to a mirror. It has been calculated that we lose about four hundred cubic centimetres of water by the lungs every day. The evaporation of water entails some loss of heat, and expired air is always warmer than the air that was breathed in. The lungs therefore are of assistance in regulating the heat of the body. In hot weather a dog lies on the ground and pants and

by means of this increased frequency of respiration gets rid of an excess of heat. A man achieves the same purpose by an increased output of sweat. Expired air, as well as containing carbon dioxide and water vapour, also contains traces of other gases such as hydrogen, sulphuretted hydrogen and ammonia.

CHAPTER VI

EXCRETION

In studying the cell we saw that it was essential to life that the waste products of metabolism should be promptly eliminated. In the human body the function of excretion is carried out by the kidneys, the skin, the lungs and the bowel. The excretory action of the lungs has been described It now remains to give an account of the activity of the kidneys and the skin. Of these two excretory organs the kidneys are by far the more important. Indeed if we except gaseous waste products, water, and a small quantity of salt, the elimination of waste matter is almost entirely the work of the kidneys.

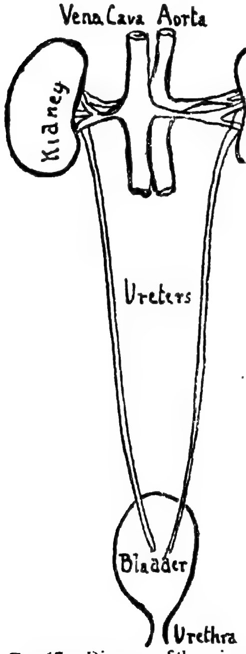


FIG. 17.—Diagram of the urinary tract, showing the blood supply of the kidneys.

These two organs lie in the upper part of the abdomen, one on each side of the vertebral column. From each emerges a long channel called the ureter, which is the conduit by which the urine passes to the bladder (see Fig. 17). If we regard a

gland as being a membrane on one side of which are blood vessels, and on the other a free surface, or duct, the kidneys may be looked upon as extremely complex glands. In the kidneys there are actually thousands of minute glands in the form of canals lined with epithelium, each of which is known as a uriniferous tubule. The uriniferous tubules begin in the outer portion, or cortex, of the kidney as dilated bulbs, called Malpighian corpuscles. These are surrounded by a fine network of capillaries from which waste products pass into the lumen of the tubule. It would be more correct to say that the bulbous blind beginning of a tubule (Malpighian corpuscle) is not surrounded by capillaries, but that these have invaginated its walls as a finger can invaginate a soft rubber ball (see Fig. 18). The capillaries, therefore, appear to be inside the bulb, although they are still external to its walls. If a kidney be cut in half and the cut surface be examined with a magnifying glass, it will be seen to have a striated appearance. These striae radiate from the cavity within the kidney (the pelvis) towards its surface. The striated appearance is given to the kidney by the fine lines of the tubules. Their course is not a straight one, as the striation would seem to indicate, for on microscopic examination the tubules are seen to make loops. At one time it was believed that the kidney

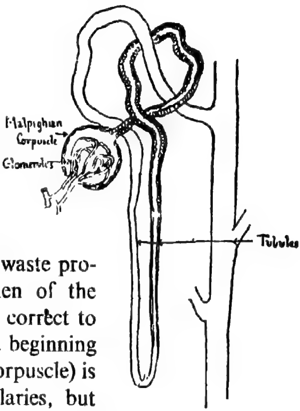


FIG. 18.—Diagram showing Malpighian corpuscle, with tuft of capillaries (G l o m e r u l u s). The secreting epithelium is shown only in a part of the looped tubule. (After Horner Smith, *Physiology of the Kidney.*)

acted merely as a filter, which allowed certain constituents of the blood plasma to pass through the walls of its tubules. Excretion is now known to be something more than a mechanical separating of impurities from the blood plasma. The kidney is a machine which expends vital energy in performing this work. The cells lining the tubules do not merely serve passively as a strainer; they actively excrete. The urine is therefore not a filtrate, but a product of the excretory activity of the tubules.

The kidney has several functions. Not only does it excrete waste material and water, but it controls the reaction of the blood by excreting acid sodium phosphate. It also regulates the composition of the blood plasma. Should there be a rise in any of the normal constituents of the blood plasma, the excess is got rid of by the kidneys. If, for example, the percentage of sugar in the blood increases, sugar appears in the urine until the quantity in the plasma falls to normal. Should abnormal constituents be present in the plasma, these also are got rid of by the cleansing action of the kidneys. In a case of typhoid fever, typhoid bacilli are frequently found in the urine. Drugs are eliminated in the same manner; senna, potassium iodide, potassium bromide and arsenic are all thrown out by the kidneys.

The excretion of urine depends upon three chief factors: the blood pressure in the capillaries, the velocity with which the blood flows, and the physiological activity of the cells lining the uriniferous tubules. The first two of these factors depend on the state of the circulatory system, the third on the condition of the kidneys. Should the arteries supplying the kidneys (renal arteries) dilate, more blood is brought to them, and consequently excretion becomes more active. Should the arteries become constricted, the output of urine falls. Constriction of the blood vessels of the skin is usually associated with a dilatation of the renal arteries and a rise

of pressure. This explains the increased output of urine during the cold weather. The effect of a fall in blood pressure is shown by the small amount of urine passed in cases of heart failure. Because the flow of blood through the kidneys is sluggish less urine is produced. If the blood pressure falls below 40 mm. of mercury, urinary excretion stops altogether. The drinking of a large quantity of fluid causes a prompt rise in the amount of urine excreted. This is due to water being absorbed into the blood stream, which increases the blood volume and thereby raises the blood pressure. The blood volume and pressure is soon corrected by the excretion of a large quantity of urine.

The third factor that determines the output of urine is the excretory activity of the cells lining the tubules. This is affected adversely by many diseases. For example, the toxins formed by the organisms which cause scarlet fever, typhoid, diphtheria and tonsillitis may all diminish the efficiency of the kidneys by their action on the tubules. Alcohol, taken in excess and over a long period, may also injure the cells of the kidney and reduce their excretory powers.

The urine percolating along the tubules collects in the renal pelvis, or cavity within the kidney. From here it passes along the ureters into the bladder, its arrival there being assisted by a series of peristaltic waves travelling along the ureters. Because the descent of the urine down the ureters is an active process, the urine finds its way into the bladder discontinuously. Each ejection into that viscus synchronises with a peristaltic wave travelling along the ureter. By modern methods of examination (cystoscopy) the efflux of urine into the bladder can be observed, and the functional activity of the kidneys assessed. Much use is made of this method of examination by specialists in urinary diseases. If while the efflux is being observed some dye (such as indigo carmine) be injected into a vein, it will be excreted into the bladder

within ten minutes. A considerable delay in the time of the appearance of the blue in the bladder is generally indicative of poor functioning of the kidneys. By noting the moment of the appearance of the dye at each ureteric orifice, the relative efficiency of the two kidneys can be compared.

Another extremely useful modern method of investigating the state of the kidneys is to inject into a vein a fluid that is opaque to X-rays. An ordinary X-ray photograph does not reveal any of the structure of the kidney, but if an opaque fluid like uroselectan be administered intravenously beforehand the injected fluid is excreted by the kidneys and outlines their structure whilst it is being excreted. This method of examination is called excretion pyelography. By means of it not only the pelvis of the kidney but the ureters also are revealed (see Plate II).

From the bladder the urine is voided by the urethra. The outlet of the bladder into this channel is guarded by a strong circular muscle (the sphincter), the contraction of which closes the urethra except during the act of urination. Urination, or micturition, is actually a very complicated act co-ordinated by the central nervous system. When a certain amount of urine has collected in the bladder the rise of pressure within that viscus stimulates the sensory nerves supplying its walls. This sends a message to the micturition centre situated in the lower part of the cord, and initiates the reflex action of micturition. Strong contractions of the muscle coats of the bladder follow and at the same time the sphincter relaxes. In early life micturition is entirely automatic, the bladder emptying itself whenever the pressure within it rises above a certain level. But with education micturition is brought under the control of the will. In an adult the sensory impulses produced by a full bladder ascend from the cord to the brain, so that he becomes conscious of a desire to urinate. He can, to a certain extent, either aid or

inhibit the reflex of micturition. This control over the bladder sphincter is at first established in children during the daytime, and it is only after prolonged education that it is maintained during sleep. In mentally deficient children control is never established. This does not mean that the common trouble of bed-wetting is a sign of low mentality. On the contrary, bed-wetting is more frequently found amongst intelligent, excitable and nervous children. Usually it is a sign of some hidden anxiety, or some lack of adjustment to environment. The desire to pass urine frequently is a common manifestation of an anxious state. Athletes awaiting the start of a race sometimes experience this highly inconvenient symptom.

A common disease of the kidney is known as Bright's disease. Actually a number of different conditions are included under this heading. Bright was a Guy's Hospital physician who in the last century established a connection between degenerative changes in the kidney and the presence of albumen in the urine. The discovery of albumen in the urine usually indicates a faulty working of the kidneys. It means that albumen from the blood plasma is being allowed to pass through the renal tubules, and thus be excreted in the urine. At the same time the damaged tubules fail to achieve what is one of the most important of their functions, namely, the elimination of fluid. When this failure is very marked, fluid, instead of being excreted, collects in the tissues and causes swelling, or oedema, of various parts of the body. The fluid is more likely to collect in dependent parts, or where the tissues are very lax, that is to say, in the legs and in the eyelids. Hence the puffy face and swollen legs of the sufferers from advanced Bright's disease. A faulty elimination of waste products also leads to a condition of toxaemia, or chronic poisoning, which may end in uraemia and death. It must not be assumed, however, that the presence of a small

amount of albumen in the urine is necessarily a sign of Bright's disease. It is often transient and of no great significance.

The Skin

Although in some animals (for example, the frog) an absorption of oxygen and an elimination of carbon dioxide take place through the skin, very little interchange of gases occurs by this route in human beings. Whereas we lose daily about 900 grams of carbon dioxide by means of the lungs, we only excrete about 9 grams through our skin. The amount of oxygen absorbed through the skin is even less. The skin may, however, be looked upon as an important means of getting rid of water, inorganic salts, traces of urea, and occasionally, when the kidneys are diseased, of larger quantities of the last-named substance. Certain drugs may also be eliminated and others be absorbed through the skin. Use is made of this in medical treatment. For a long time mercury was administered to syphilitics by the method of inunction, that is, by rubbing a mercurial ointment over the surface of the body until it disappeared. Much of the former fame of Aix-la-Chapelle as a centre for the treatment of syphilis was due to the skill with which the professional rubbers carried out inunction. Although this method of treating syphilis is now seldom employed, advantage is still taken in modern medicine of the absorptive action of the skin. The recently discovered male hormone, testosterone (the internal secretion of the testicles), may be administered as an inunction. The female hormone, oestrin, is absorbed through the skin so readily that if the back of a mouse be lightly touched every day with a small brush dipped in this secretion profound changes may be produced.

The elimination of drugs through the skin is effected by means of the sweat. The amount of water lost by the skin in

PLATE 2

The calices, pelves and ureters have been rendered visible by an intravenous injection of a chemical substance which throws a shadow during excretion by the kidneys. The film was exposed fifteen minutes after the injection was made

this way varies from 500 to 200 cubic centimetres per diem. When evaporation keeps pace with excretion the sweat is termed invisible or insensible, in contradistinction to visible or sensible sweat. The factors that are of the greatest importance in determining the amount of sweat which is produced are the level of the external temperature and the amount of muscular activity that is taking place in the body. A high temperature is associated with a dilatation of the skin capillaries and with an increased activity of the sweat glands. A low temperature is associated with constriction of the capillaries and an absence of visible sweat. But the activity of the sweat glands is not solely determined by temperature. This is clearly shown by the occurrence of nervous sweating. A severe psychic shock may be followed by the pouring-out of sweat. This is because the sweat glands are supplied (that is, stimulated) by nerves derived from the sympathetic system, which is invariably thrown into action by fear. In the case of nervous sweating the skin, instead of being engorged with blood, is pale, owing to constriction of its capillaries. A similar type of sweating may also be associated with nausea, and for the same reason, namely, stimulation of the sympathetic nerves.

Three other functions of the skin have to be considered, namely, the functions of protection, of regulation of heat loss to the body, and the physiological action of light upon the skin. It is obvious that the skin is a protective wrapping to the body, for its outer layer is composed of hard resisting cells (the epidermis) that protect the tissues against mechanical, chemical and bacterial injuries. An intact skin offers an excellent first line of defence against the entry of germs; for example, the organism of syphilis. Where protection against mechanical injury is particularly called for, the skin develops thickness, as on the sole of the foot, and on the palms of the hand.

But the skin is not only a covering, it is also a sense organ. In order to fit it for this important function it is plentifully supplied with nerves, which end in specialised organs called tactile corpuscles. These are the organs of touch. They are especially numerous in the areas of skin where hair is absent, and most plentiful of all in the tips of the fingers. Fine nerve plexuses are also found around the hair follicles. This allows the hairs to be used by animals for assessing pressure. It is their connection with the central nervous system that makes a cat's whiskers such a valuable organ of sense. There is also in the skin another variety of nerve ending which permits us to differentiate between heat and cold. The surface of the skin may be looked upon as being marked off into minute areas, each of which subserves a special sense, those of pressure, pain, heat and cold. It is probable that each of these areas is provided with a different type of end-organ for this purpose.

Heat Regulation in the Body

One of the most important functions of the skin is to help in regulating heat production and heat loss. The heat produced by the body is the result of the oxidation processes occurring during life, and from the point of view of body temperature animals may be divided into two great classes, poikilo-thermal animals and homoio-thermal animals. Popularly these are known as cold-blooded and warm-blooded animals respectively. Actually these terms are inaccurate, for a reptile's blood is warm even though it be colder than that of a mammal. The real distinction between a warm-blooded (homoio-thermal) and a cold-blooded (poikilo-thermal) animal is that in the latter the temperature of the blood varies directly with that of the surrounding air. In such animals there is no well-adjusted heat-regulating mechanism such as exists in homoio-thermal animals. This

being so, reptiles, fish and amphibians are under a disadvantage, as compared with mammals, for a constant temperature renders an animal more independent of its surroundings. A mammal can support changes in temperature that a snake would find it difficult to tolerate. The skin of a mammal plays an important part in this heat-regulating mechanism of the body. It is one of the means by which man's blood retains its temperature of between 98 and 99 degrees Fahrenheit even when he moves from the Equator to the Pole, works in a stoke-hole or in a refrigerating chamber, wears a fur coat or a bathing-suit. The centre for the regulation of temperature lies in the bulb (hind-brain). Afferent impulses reach this from the skin and efferent impulses leave it for the muscles. When the skin is cold, sensations from it reach the heat-regulating centre and messages are sent from thence to the muscles. These messages result in an increase of oxidation and therefore in an increased output of heat. A high external temperature produces the reverse effect, namely, a diminished oxidation in the tissues. But heat is regulated not only by increased or diminished production, but also by increased or diminished loss. There are two methods by which heat is lost from the surface of the body, by irradiation, and by the evaporation of sweat. If it is necessary that more heat should be lost from the skin, dilatation of the skin capillaries takes place, so that more blood is brought to the surface and more heat irradiated into space. At the same time there is an increased excretion of sweat, and heat is lost by its evaporation. In a certain papal procession a small boy was gilded all over in order that he might represent a golden cherub. He died the same night, and the scientists at the time believed that his death was due to the excretory function of the skin having been put out of action. This was not the case; the boy died because of interference with the heat-

regulating mechanism of the skin. If an animal with a delicate skin, such as a rabbit, be shaved and covered with an impermeable varnish, it dies of cold, but if it be kept wrapped up in cotton-wool it may survive.

In addition to forming sweat the skin also secretes sebum, a natural lubricant prepared by the sebaceous glands. When the fine ducts of these glands are blocked up with dirt and other material they give rise to the familiar blackheads. An acute infection of a sebaceous gland may also result in a boil. A carbuncle may be regarded as a number of boils that have run together and involved a considerable area of subcutaneous tissue (tissues subjacent to the skin). Both of these eruptions generally indicate a state of lowered vitality of the body.

If the skin be exposed to an excess of ultra-violet irradiation it may be so irritated as to result in inflammation and even ulceration. Repeated exposure to smaller doses leads to pigmentation, the degree of pigmentation varying in different individuals. Probably this is a safety mechanism, the pigment protecting the skin from excessive action of the rays. Another action of ultra-violet light on the skin is the conversion of a fat found there into vitamin D. This subject is dealt with more fully in Chapter III.

Sufficient information has now been given to indicate that the skin is much more than a protective covering to the body. It is a highly specialised organ, and the complexity of its structure and function is only now being discovered. As an example of the close connection that exists between the skin and other systems in the body may be cited the fact that skin eruptions are often associated with abnormal psychological states. The historical cases of stigmata and the skin eruptions following a nervous breakdown show how intimate is the relationship between the skin and the central nervous system.

CHAPTER VII

THE LIFE OF MOVEMENT

THE body is a machine capable of adjusting itself to changes in its environment. Adaptation is life, and one of the adaptations made by the body is by movement. How movement is brought about will be the subject of this chapter. In an organism like the amoeba the machinery of movement is very simple. It is dependent on the two properties of irritability and contractility; by irritability the amoeba senses the existence of something which, by means of contractility, it approaches, or else seeks to avoid. The movement is the response to a stimulus, the amoeba approaching or retiring according to the nature of the stimulus. The same principle exists in human movement, although the machinery that is set in action is more complex. To the stimulus received through certain receptor or receiving organs (the eye, ear, skin, etc.), the body responds by means of certain effector machinery, in this case the muscles. By the affector organs the body is notified of changes in its environment and by its effector organs it adjusts itself to these changes. In the present chapter the effector organs, that is to say, the muscles, will alone be described.

FIG. 19 —Striped muscle fibres.

In the human body are found three classes of muscle fibre which differ histologically and physiologically, that is, in structure and in function. The three types of muscle fibre

are striated or striped, smooth, and cardiac (or imperfectly striated) muscle fibre. These three different structures of muscle, striated, unstriated and partly striated, are exemplified by the voluntary muscles of the limbs, the involuntary muscles of the intestine, and the heart muscle, respectively. When examined under the microscope striated muscle fibres are seen to be marked with alternate transverse bands of light and shade (see Fig. 19). These bands are the outward signs of an internal structure which is too complicated to be described briefly. All that it is necessary to state is that each muscle fibre is composed of a large number of delicate fibrils embedded in a semi-fluid substance and surrounded by a structureless sheath. A large number of muscle fibres (about one inch in length) go to make up a muscle, the fibres being held together by loose connective tissue. The whole muscle is itself surrounded by a connective tissue covering. It ends commonly in a tendon, which is composed of dense white connective tissue fibres (see Fig. 4). Because striated muscles are generally attached by means of their tendons to bones they are sometimes called skeletal muscles, and because they contract through the action of the will they are also termed voluntary muscles. As each end of the muscle is attached to a bone, contraction will draw the two bones together. When, as often happens (especially in the limbs), the two bones are hinged together, contraction will cause either straightening of the limb (extension) or bending of the limb (flexion). The attachment of the muscle to the less movable bone is known as its origin, and its attachment to the more movable bone as its insertion. For example, the deltoid muscle covering the shoulder joint has its origin in the collar-bone and shoulder-blade, and its insertion in the humerus. Contraction of this muscle causes an outward movement of the arm (abduction).

Much of our knowledge of the physiology of muscles has

been derived from the study of what are known as muscle-nerve preparations. Usually the preparation that is used is the gastrocnemius muscle (calf muscle) of a frog, together with its attached sciatic nerve. By fixing one end of the muscle to a clamp and attaching the other free end to a movable lever, the movements of the muscle can be recorded on a revolving drum, similar to that used for barometric reading (see Fig. 20). A slow contraction and relaxation of the muscle will be recorded by this apparatus as a gradual curve, and a rapid contraction and relaxation as an abrupt upward and downward stroke. The surface on which these lines are traced is usually a piece of glazed paper coated

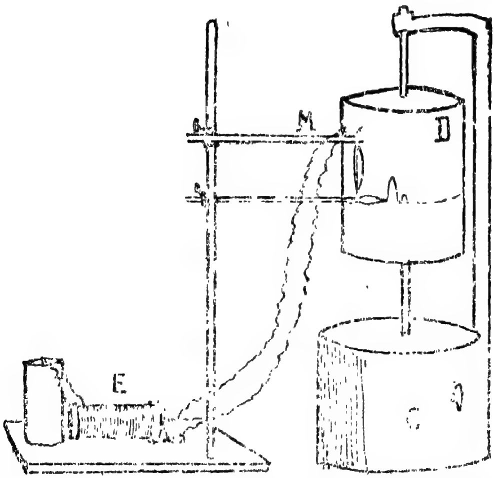


FIG. 20.—Apparatus for recording contractions in a muscle. E, electric coil for stimulation of the nerve. M, clamp for muscle-nerve preparation. D, revolving drum on which contractions are recorded. C, clockwork mechanism for drum.

with lamp-black and the speed of the rotating drum can be regulated as desired. The stimulus to the nerve which is generally employed is an induced, or faradic, electric current.

When a faradic current is applied to the nerve of a muscle-nerve preparation, the muscle gives a twitch, the contraction period lasting 0.04 of a second and the relaxation period 0.05 of a second. This twitch is preceded by a fleeting moment when nothing at all happens even though the electric shock has been given (see Fig. 21). This is known as the latent period of the muscle-nerve preparation. If a number of electric shocks are applied, each arriving before the muscle has had time to finish relaxing from the previous one, the muscle contracts to each stimulus and never completely relaxes between them. The muscle is then said to be in a condition of incomplete tetanus (see Fig. 22). If the speed of stimulation is still further increased so that each succeeding stimulus arrives before the muscle has had time to relax at all, a condition of complete tetanus results (see Fig. 23). It has been shown by experiment that all voluntary contractions of our muscles (even of such short duration as the winking of an eyelid) are tetanic in nature. In other words, muscle contraction is never a single twitch, but is a more prolonged shortening produced by a summation of impulses travelling along the nerve at the frequency of about fifty per second.

When a muscle contracts many changes occur in it besides shortening. One change that is not obvious, but which can be demonstrated by suitable apparatus, is that it develops within it what is known as a 'current of action'. That part of the muscle which is contracting becomes negative to that part which is quiescent, and a current that can be measured by a galvanometer flows from one part to the other. In addition to these electrical disturbances, chemical changes

take place in the muscle. Resting muscle is alkaline in reaction, but if a muscle be tested after it has contracted repeatedly, its reaction will be found to have become less

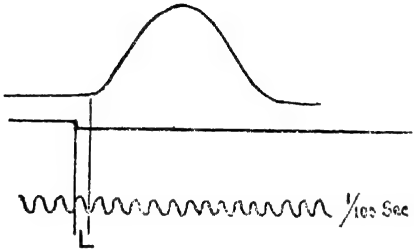


FIG. 21 Curve of muscle contraction from a single shock. L represents the latent period or interval between the passage of the current and the beginning of the contraction.

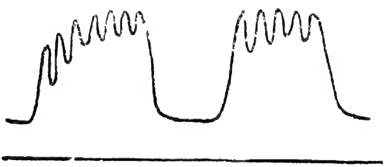


FIG. 22.—Muscle curve with repeated stimuli The muscle is in a state of incomplete tetanus.

FIG. 23 – The speed of stimulation has been increased so that each stimulus arrives before the muscle has had time to relax. Complete tetanus results.

alkaline, and eventually (when overdriven) acid. This change in reaction is explained as follows. Energy is stored up in muscle as sugar and glycogen. This, when it breaks down, forms lactic acid, and eventually carbon dioxide and water. Hence the acidity of the over-stimulated muscle of the hunted animal. Another change that occurs in a muscle when it contracts is a rise in its temperature. When we feel cold we move about, or slap our arms across our chests in order to obtain warmth, instinctively realising that by putting our muscles into action we achieve this object. Nature's remedy, shivering, is another device for increasing the output of heat in muscles.

It should be realised that even when the muscle is at rest it remains slightly contracted. This contraction is necessary for efficient working, for much time would be lost if muscle slack had first to be taken up before any movement occurred. The slightly contracted state in which a muscle remains is referred to as its tone, and much of the body heat is supplied by it. Obviously the output of heat is markedly increased when the muscles are fully contracted. The fact that a muscle is slightly contracted even when it appears to be at rest is of some practical importance. In the case of a tranquil-minded man with relaxed muscles the amount of work that these are called upon to perform whilst he remains inactive is not very great. But many of us are neither relaxed nor tranquil-minded. We go through life tense in mind and body, and the energy which is lost in this way is by no means negligible. There is little doubt that the hurry and strain of modern life is a source of great wastage of energy. How many Westerners are able, like an Oriental, to lie or sit with relaxed muscles and, like him, to move with the minimum of effort? Part of the Oriental's ability to relax his muscles is undoubtedly due to the hot climate, heat having the power to relax muscle fibres. But a great deal of the

relaxation is due to his living under less strain and having a different attitude to life.

Plain or unstriped muscle is found in the walls of all the great hollow organs, in the alimentary canal, in the circulatory system, and in the respiratory and genito-urinary tracts. Unstriped muscle fibres are also found in the eye (the iris and ciliary muscle) and in the skin. It is the contraction of the unstriped muscle fibres of the skin that erects the hair of the angry cat, and in man is responsible for the production of what is called 'goose-flesh'. Unstriped muscle differs not only in appearance from striped, but in the source from which it derives its nerves. Striped muscle is supplied by nerves from the brain and spinal cord, unstriped muscle from what is known as the sympathetic system. Whilst the activity of striped muscle is to a great extent under the control of the will, unstriped muscle is automatic in action. By special training adepts in Hatha Yoga (the Yoga of body control) attain a certain amount of power over the sympathetic system, and consequently over involuntary muscles. It is this power which allows them to do what is impossible to men ordinarily. Usually the stimulus to which unstriped muscle responds is pressure, or stretching. An excellent example of this is provided by the unstriped muscle of the bowel (see page 33). Like striped muscle, unstriped muscle normally remains in a state of mild contraction; for example, the cavity of the empty stomach is more or less obliterated by the tone of the gastric muscles. In certain debilitated individuals this tone is deficient and such a person is said to suffer from a dilated or dropped stomach. Stretching no longer acts as a stimulus to such an organ and it remains permanently dilated. A similar condition in the bowel may be the cause of an obstinate constipation.

The third kind of muscle fibre, namely, that out of which the heart is formed, is partially striated, and possesses some

of the features of voluntary and some of the features of involuntary muscle. It differs from voluntary muscle not only in being outside the control of the will, but also in having a much longer latent period. It is, therefore, unable to enter into tetanic contraction. This is probably due to the fact that the metabolic changes that take place during contraction are slower than those of voluntary muscle.

Two phenomena occurring in muscle remain to be described, fatigue and rigor mortis. If a muscle-nerve preparation be stimulated repeatedly it eventually ceases to contract on account of fatigue. Should the electric stimulus then be applied directly to the muscle it can still be made to contract. This shows that the fatigue from which it suffered was somewhere in the nerve and not in the muscle itself. Other experiments have proved that nerve fibre is practically indefatigable and that the seat of fatigue in a tired muscle-nerve preparation is in the nerve endings. These delicate structures are easily put out of action, for example, by drugs. If an extract from certain barks found in South America be painted on a muscle, stimulation of its nerve no longer brings about a contraction. The drug curare causes a temporary break between the nerve and muscle. It was for this reason that Indians dipped their arrow-heads in it, so that they might paralyse, as well as wound, their prey. The fact that the nerve endings are the primary seat of fatigue does not mean that the muscle itself is indefatigable. If direct stimulation be repeatedly applied to a muscle in the end it ceases to contract. This is probably due as much to the accumulation within it of waste products as to the exhaustion of its fuel. If the tired muscle be given sufficient rest it recovers its contractility, provided always that its blood supply is intact.

Rigor mortis, as its name implies, is the stiffening of the muscles that follows death. It is due to coagulation of the

muscle proteins and it may begin from a quarter of an hour to four hours after death. At a later period it begins to pass off, as the result of the breaking-down of the tissues. If death has been preceded by a long wasting disease, or by great exertion (as in the case of a hunted animal), rigor mortis sets in very rapidly. This is due to the large amount of lactic acid present in the muscles. Rigor mortis is associated with shortening of the muscles and permanent fixation in the posture assumed just prior to death. The rigidity of the corpse must often have given great trouble to murderers who have wanted it to appear that their victims had died peacefully in bed. It is by the completeness of the rigor mortis, or of the subsequent softening, that the police surgeon gauges the time which has elapsed since the death of the victim. As the time of onset of these changes is very variable the police surgeon's deductions are liable to be erroneous, however accurate they may be in detective novels.

CHAPTER VIII

THE CENTRAL NERVOUS SYSTEM

THE central nervous system is the means by which the various activities of the body are co-ordinated and by which the whole organism is made aware of changes in its environment. In man it has been very highly elaborated in order that adjustments to inner and outer changes may be rapidly effected. The chief structures in the central nervous system are the brain and spinal cord and the vast number of nerves to which these give rise. The whole of this great co-ordinating system, with its headquarters in the brain and cord, may be likened to a vast collection of offices which keep in touch with the working of the body by means of an elaborate system of telegraph wires. Speaking generally, the brain concerns itself with the psychic life and with the messages arriving through the special senses, whilst the spinal cord deals with movement and with the other activities of the body. Actually, the part of the nervous system to which is delegated the all-important work of supervising the vital activities of the body is the junction of the brain and the cord, that is, the region of the bulb. The bulb (which is included in the description of the brain) contains the centres which regulate body temperature, blood pressure, respiration and carbohydrate metabolism.

Before dealing with the anatomy of the central nervous system, it will be necessary to describe the morphological unit of which it is built up, namely, the nerve cell, or neurone. This is a much-specialized cell from which have grown out one or more branches, or processes. In a typical neurone the cell body gives rise to two processes, one short

and branched called the dendron, and the other long and less branched called the axon (see Fig. 24). What is popularly known as a nerve is really a big collection of axons of nerve

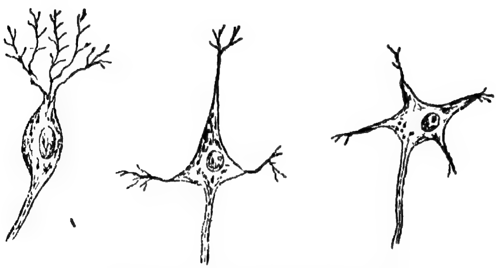


FIG. 24.—Different types of nerve cells.

cells bound together by a packing of connective tissue. Since a nerve contains many nerve fibres, a section through it resembles a section of a marine cable (see Fig. 25). On the cut surface we note a great number of insulated wires held together by a certain amount of packing material. Nor is the resemblance to a cable only a superficial one. If the long process (axon) that grows from a nerve cell be suitably stained and examined microscopically it will be seen to be made up of two parts, a central core, or axis cylinder, and a thick covering of fat known as the myelin sheath. Outside this fatty covering is a thin outer layer of connective tissue, called the neurilemma. The central core, or axis cylinder, is the active part of the nerve fibre along which the nerve impulse passes, and the myelin and connective tissue sheaths are insulating material which has the same function as the rubber which surrounds

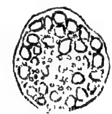


FIG. 25.—Section through a nerve, showing constituent nerve fibres.

the marine cable. The sheath prevents leakage of current. It is to the fat in the myelin coat that the white colour of a nerve is due. The nerves of the sympathetic system are devoid of fat and consequently are greyer in colour than the nerves in other parts of the body. These grey nerves are described as non-medullated, in contradistinction to the white medullated nerves which make up the rest of the central nervous system.

The nerve fibre, or axon, is an offshoot of the cell body and depends for its nutrition on this structure. When a large composite nerve, such as the sciatic, is divided, those parts of its constituent nerve fibres which still retain connection with the parent cell survive, whilst those parts which have been separated from them die. This does not mean that once a nerve has been cut it is for ever destroyed. Fortunately, repair of a divided nerve takes place by the nerve fibres which still retain connection with their cells growing until they reach their original destination. Surgeons take advantage of this power of a nerve to regenerate in dealing with severed nerves. They suture together the two halves of the divided nerve, not with any hope that they will be welded together, but in order that the dead half of the nerve may provide a path along which the living half grows. The dead portion of the nerve merely acts as a guide to the growing portion.

From the end of the nerve cell opposite to the axis cylinder is given off the shorter branch, the dendron. Some cells have several dendrons and others only one. These much-branched processes serve to form connections with the dendrons in neighbouring cells. They are the links along which nerve impulses pass from one cell to another. Just as in a telephone system the operator can connect up one subscriber with another by 'plugging in' on a switchboard, so in the human body impulses may be switched in one direction or another by the connections between dendrons. It is still a debated

point whether there exists actual continuity, or only contact, between the dendrons of two connected cells. At one time the latter supposition was favoured, and on it was based a theory of sleep. Sleep, it was supposed, was caused by the retraction of dendrons in the nerve cells of the higher centres of the brain. This separation of dendrons interrupted the flow of nerve impulses from one cell to another and consequently brought to rest all mental processes. Ingenious as this theory may be, it cannot be supported by any reliable observations.

Having studied the minute structure of the central nervous system, it will now be necessary to look at the system as a whole. As we have seen, it consists of the brain and spinal cord and the innumerable nerves to which these give rise. From the spinal cord, housed within the vertebral column, there issue thirty-one pairs of nerves which run to different areas in the body. The brain gives rise to twelve pairs of cranial nerves. These are chiefly concerned with the special senses of sight, hearing, taste and smell. But there exists yet another system of nerves, the sympathetic system, which is formed as a kind of offshoot from the spinal nerves. It takes its origin from the spinal nerves at a short distance from their emergence from the spinal cord. Whilst the main central nervous system (the brain, spinal cord and their nerves) is chiefly concerned with sensations and movements, the sympathetic system regulates the purely automatic functions of the body, such as the activity of glands, the constriction and dilatation of the blood vessels and the movements of the viscera. It is distributed widely through the body as a fine network which in certain areas becomes more dense, forming what are called ganglia and plexuses. The best known plexus is the solar plexus, which lies in the upper part of the abdomen. This appears as a great tangle of grey threads, and in ancient medicine it was believed to be

the seat of the emotions. Nor is this belief without some justification. It has now been found that the sympathetic system establishes connection with a very important mass of grey matter lying at the base of the brain, the thalamus. Modern research has shown that this great collection of grey matter is intimately associated with the emotional life.

If we could see the whole living web of the central nervous system spread out before us and if nervous impulses were visible, say, as light travelling along nerves, we should see this system in ceaseless activity. There would be an uninterrupted passage of sensation from all parts of the body towards the spinal cord and brain, and an unending procession of return messages in the opposite direction. For the web is a double one containing fibres of two kinds, sensory or afferent fibres, which carry incoming impulses, and motor and efferent fibres, which bear outgoing impulses. These two kinds of fibres are bound up together within the same nerve trunk, and in structure appear similar. They differ only in the direction along which the impulses travel, and in the destination to which they are being carried. Some of the nerves carrying afferent (incoming) messages have their origin in the special sense organs. These are scattered over the surface of the body and also amongst the muscles, joints and viscera. They are the intelligence agents which report to the spinal cord and the brain the state of affairs in different parts of the body. The central government is thereby informed of the temperature of the skin, the position of the limbs, the nature of the object with which the skin is in contact and, through the eye and the ear, of the impact on the body of undulations of light and sound. These intelligence agents may be divided into internal sense organs and external sense organs. The former report on the state of the body and the latter take note of conditions external to the body. The external sense organs are of particular

importance to us, for they include the special organs of sight, hearing, taste, smell and touch.

Reflex Action

Just as the nerve cell, or neurone, is the physical unit out of which the central nervous system is built, so is the reflex the physiological unit of the body's activity. As we are at present studying physiology rather than anatomy, this unit of activity is of particular interest. Briefly, a reflex action consists of an afferent impulse (one travelling towards the cord) which passes by dendrons to an efferent nerve cell and thence to a muscle or gland. In a reflex action an afferent is transformed into an efferent impulse. In other words, a reflex is the chain of events which occurs when, in response to some stimulation of an afferent nerve fibre, a motor or secretory response is obtained. It follows from this definition that for every reflex movement there must be a receptor organ, afferent and efferent neurones, and a muscle or gland that is thrown into activity (see Fig. 26). A cardinal

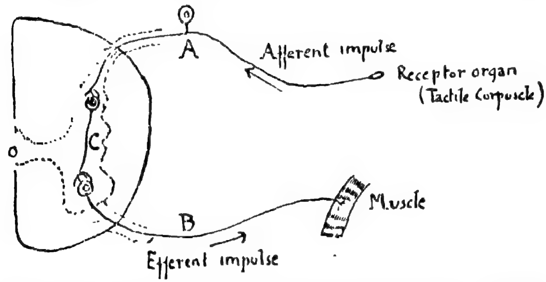


FIG. 26.—Transverse section through left half of the cord, to illustrate reflex action. A, afferent (sensory) neurone, with cell body in the posterior root ganglion. B, efferent (motor) neurone, terminating in muscle fibre. C, connecting neurone. In some cases the neurone bearing the afferent impulse connects up directly with that bearing the efferent impulse. Here the impulse is made by means of a third nerve cell.

property of all reflex actions is that the responses are purely automatic and independent of will or desire. If the sole of the foot is tickled the toes curl and the foot is withdrawn. This happens when the subject is asleep, or under a light anaesthetic. The brain takes no part in it, for the connection between the afferent and efferent neurones lies in the cord. In this particular example of a reflex the muscular response follows a tactile stimulus. But other types of reflexes occur in the body. The contraction of the pupil is an example of a motor response to the stimulation of the eye by light. In the chapter on digestion we saw that the activity of the salivary and gastric glands was aroused by the stimulus of food. In this particular case the reflex sometimes occurred through the brain. It can be started merely by the sight or smell of food.

The great majority of reflex actions in the body are inborn, that is, they occur naturally and without training. But a reflex may also be learnt. The response of the gastric glands elicited by the ringing of a bell and by the ticking of a metronome are examples of a conditioned reflex, that is to say, one that has been learnt. This discovery that the body has the power to learn new reflexes gave an impetus to the psychological theory of behaviourism. According to this theory, not only body activities, but the whole of psychic life, is merely a collection of inborn and learnt mental reflexes.

The strength of the response of the effector organ to reflex stimulation depends to some extent on the state of the body. The action may be reduced in intensity by fatigue and many reflexes are abolished altogether in an asphyxiated animal. Reflex action is also affected by drugs. The slightest touch on the surface of an animal poisoned by strychnine will cause such an exaggeration of reflexes that it is thrown into convulsions. The toxins of tetanus (lockjaw) have a similar

action. Sedatives, such as bromides, alcohol, chloral and opium, have the reverse effect; they reduce the intensity of reflex actions and, if a sufficient quantity of these drugs be taken, many reflexes are abolished altogether. It has also been discovered that one reflex may exercise an inhibitory effect on another. This is why the introduction of a lump of sugar into the mouth will sometimes stop an attack of hiccough (reflex spasm of the diaphragm). The new reflex started by the sugar suppresses the earlier reflex involving the diaphragm.

By eliciting the superficial reflexes of the body and noting whether they are exaggerated or diminished the physician is able to obtain some indication of the state of his patient's central nervous system. The patellar or knee reflex is often used for this purpose. This is elicited by tapping the tendon by which the great extensor muscles of the thigh are attached to the tibia. The motor response to this stimulus is a kick forward of the leg and foot. Its briskness or sluggishness helps the physician to gauge the tonicity of the thigh muscles, and this in turn throws light on the state of the patient's nervous system. In certain diseases of the cord, such as tabes (locomotor ataxia), the patellar reflex is abolished altogether. In excitable and in neurotic states the response is exaggerated. But the patellar is only one of the many automatic responses that a physician may select as a test of his patient's condition. Another favourite test is the reaction of the pupil to light.

The Brain

The brain is really the expanded and highly developed upper part of the cord. The medical student who said that it was 'a bit of spinal cord with knobs on it' spoke crudely but not inaccurately. His description would certainly be justified as a description of the brain of many of the lower

animals, such as the lancelet. Even in the human embryo at an early stage the brain appears as three swellings at the end of the cord. In time these three hollow expansions develop into the fore-brain, the mid-brain and the hind-brain. They enclose three cavities known as the ventricles, which are continuous with the canal that runs down the centre of the whole length of the spinal cord. From the walls of these three swellings develop all the structures that constitute the human brain. From the hindmost swelling develop the medulla or bulb and the cerebellum. In the former lie the important centres concerned with the regulation of body processes. The cerebellum is developed from the roof of the hind-brain, which grows out to form a kind of subsidiary brain about the size of a small tangerine (see Fig. 27). The cerebellum is mainly concerned with maintaining the balance of the body. It also plays an important part in co-ordinating complicated movements, such as are used in skating, dancing and even in walking. Disease of the cerebellum often manifests itself in an inability to balance, the patient rolling about like a drunken man.

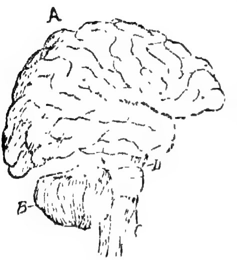


FIG. 27.—The human brain in profile *A*, cerebral hemisphere. *B*, cerebellum *C*, medulla oblongata, or bulb. *D*, mid-brain.

The Cerebral Hemispheres

The main distinguishing feature of the human brain is the size of the cerebral hemispheres. These first appear as two buds growing out from the fore-brain. Because they cannot find sufficient space in the forward position, they turn backward as they grow larger and eventually become so large

that they envelop the whole of the rest of the brain. In these enormous expansions are received all the sensory impressions of the body, and from them depart all voluntary movements. The cerebral hemispheres are also the physical basis of psychic activity. If the seat of the intellect can be located it must be placed in the layer of grey matter that covers the cerebral hemispheres. In order to provide more

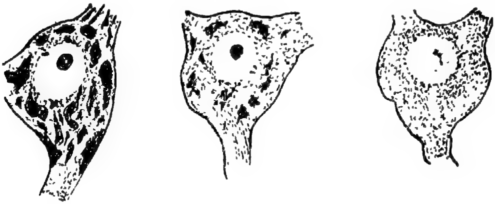


FIG. 28.—Brain cells, showing different stages of fatigue. The first is a normal cell, the second, one moderately fatigued; and the third, a cell extremely fatigued. (After Penfield and Dolley, *Physiology of the Nervous System.*)

space for this all-important surface the cerebral hemispheres are thrown into a number of folds, giving them the appearance of a shelled walnut. It is by its richness in folds rather than by its size that the brain of an intellectual man is distinguished from that of a primitive savage.

Microscopic examination of the grey layer of the cerebral hemispheres shows that it is composed of millions of nerve cells. Staining of these cells reveals the fact that they are full of particles known as Nissl's granules. These are associated with brain activity. After a period of work they are reduced in number, and in a state of exhaustion they disappear (see Fig. 28).

One of the most fascinating advances made in neurology (the study of the central nervous system) has been the

mapping-out of the cerebral cortex. So successfully has this been done that we can now allocate to most of the surface of the cerebral hemispheres its appropriate activity. We know where sensations are received and what part of the brain is responsible for the movement of voluntary muscles. We have located the centres for sight, hearing, taste and smell. These centres of activity do not correspond to those described by the phrenologist, and no physiological justification can be advanced for this science. A bump on the skull does not necessarily correspond with a high development of the underlying brain, and the localisation of activities on which the phrenologist bases his diagnosis is different from that of the scientist.

In his task of mapping out the brain the scientist has made use of several different kinds of observation. He has painfully and tediously followed the course of the nerve fibres in the body and has traced them to their termination in different regions of the brain. He has also examined brains that have been injured, or have been the site of tumours, and has correlated his findings with the symptoms from which the patients previously suffered. He has also gained valuable information from experiments on animals by stimulating various areas, or by injuring them, and recording what activities were elicited or eliminated. The situation of some of the more important centres in the cerebral hemispheres is indicated in Fig. 29.

For a long time the scientist was unable to discover the precise function of the foremost part of the cerebral hemispheres, and because destruction of them produced no disability he labelled it 'the silent area'. A hospital case observed during the last century threw some light on this area. A labourer was admitted to a hospital after having had the greater part of the front of the brain destroyed by a crowbar which had been driven through his orbit. He re-

covered without any paralysis or other physical disability. But his whole character had been altered. From being a hard-working honest man he had become a wastrel, a liar and a cheat. Subsequent observations on other cases have confirmed the impression that it is the foremost part, or

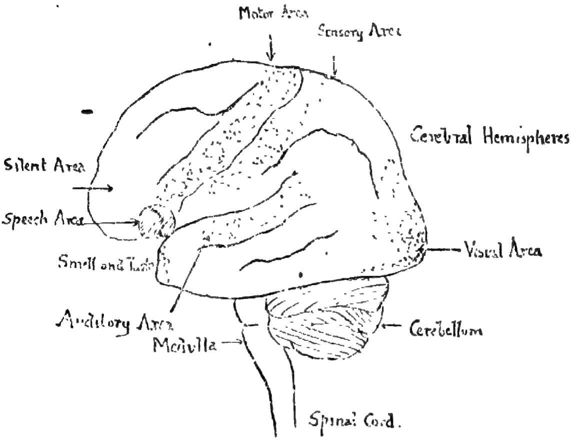


FIG. 29.—Diagram to illustrate some of the more important centres in the cerebral hemispheres.

so-called silent areas, of the cerebral hemispheres that is the physical basis of those qualities which distinguish a human being from an animal. This does not mean that an animal is a cheat and a liar, but that it does not possess the superior faculties of man.

As an example of the precision with which scientists are now mapping out the centres in the brain may be given the discovery of the speech centres. A tiny region has been found on the left side of the brain only which is concerned

recuperating from mental fatigue. Some investigators have even stated that gymnastics ranks almost as high as the study of mathematics in producing brain fatigue.

The action of alcohol on the brain is of interest in this connection. It has frequently been stated that alcohol stimulates mental activity, yet careful experimentation has proved that it is more likely to affect adversely the efficiency of the cerebral hemispheres. Various tests have been made which showed that although those who had taken alcohol believed that their subsequent work had been done expeditiously and well, this work on examination was found to be inaccurate. For example, experiments with reading aloud revealed the fact that although the individual read faster after taking alcohol he made more mistakes. It is true, nevertheless, that many people are capable of making a better speech after taking a little alcohol. This is due to the alcohol removing the inhibitory actions of fear and of concern with other people's opinion. Alcohol is not a stimulant of the central nervous system, but in spite of this fact it has its utility. Looked at as a machine, the mind and body of man seldom run smoothly. The mind is subject to innumerable strains and its working is hampered with the friction produced by fear and anxiety. A little alcohol tends to remove these hindrances and to allow the machinery to function more smoothly. It was no mere accident that every nation, indeed almost every tribe, has independently discovered a means of making alcohol.

Sleep is the means by which nerve cells recover from their fatigue, and since most of us spend a third of our lives asleep we are naturally interested in it. But although there may be many theories, we are still uncertain as to the real nature and cause of sleep. Some investigators claim to have discovered a sleep centre in the region of the middle brain. According to another theory, sleep is merely the result of

the cessation of the stream of afferent impulses which reach the brain from the outside world; and according to yet another, it is due to a lessened flow of blood through the brain. All these theories are inadequate, and it is better to confess that we do not understand the mechanism of sleep.

CHAPTER IX

THE SPECIAL SENSES

THE function of the special senses is to inform the body of changes in its external environment. Herbert Spencer regarded life as a continuous adjustment of internal to external relationships, and the special senses are the avenues along which we receive all our impressions of the external world. All our knowledge is based on the information that we have received through these channels. The special senses may be regarded as the outposts of the central nervous system, each outpost being equipped with its own specialised form of nerve ending. As we have seen, the messages received by these outposts are recorded in different centres in the brain, although when we experience a sensation we do not locate it in our brain. When we look at the sun we do not say that we experience a commotion in the occipital region of our cerebral hemispheres. Instead, we project our sensations outward into the external world. In this respect the special sensations differ from the common sensations of hunger, thirst, fatigue, muscle sense, etc., which we refer to our own body. The sensations of heat and cold are on the borderline between these two. When we touch a cold object we refer the sensation to the object. We do not say, 'my hand is cold', but that 'there is something which is cold'. The special senses will now be considered separately.

Sight

The eye may be looked upon as a contrivance whereby certain afferent nerve endings can receive the stimulation of light waves. In order that we may appreciate an object, a

picture of it must fall upon the nerve endings of the optic nerve, and this is accomplished by the eye. The eyeball is composed of three coats enclosing a transparent medium through which light travels to the spread-out endings of the optic nerve (see Fig. 30). The outer, or sclerotic, coat forms the white of the eye. It is tough and resistant and gives shape to the eyeballs. The middle coat, or choroid, is

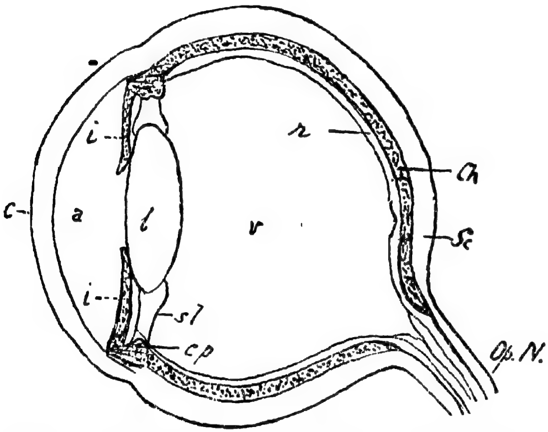


FIG. 30.—Diagram of the eyeball. C, cornea. *a*, aqueous humour. *l*, lens, *s.l*, suspensory ligaments of lens. *cp*, ciliary processes and muscles. *i*, iris. *v*, vitreous humour. *r*, retina. *Op.N.*, optic nerve. *Ch*, choroid. *Sc*, sclerotic.

highly vascular and is the main source of nourishment to the eye. The innermost coat, or retina, is formed by the spreading-out of the endings of the optic nerve. It is the functioning coat of the eye which is sensitive to light rays. The front part of the sclerotic, forming the cornea, is modified so as to be transparent. Just behind it lies a chamber filled with a

transparent fluid called the aqueous humour. The posterior wall of this chamber is formed by the lens, which has the function of focussing the light rays on the most sensitive part of the retina. Between the lens and the retina is another chamber filled with a transparent jelly-like substance, known as the vitreous humour. All the media through which the light has to pass are necessarily transparent, and if this transparency be lost, as in cataract (an opacity of the lens), vision is either damaged or destroyed.

In order that we may be able to see an object distinctly, light rays from it must be brought to a focus on the retina. Should the light be focussed a little in front of, or a little behind this sensitive structure, the image will be blurred. Focussing is brought about by the lens. This is suspended between the aqueous and vitreous chambers by means of a number of small cords, the suspensory ligaments. When these ligaments are slackened by the ciliary muscles drawing forward their point of origin, the lens, by virtue of its elasticity, assumes a more spherical form. By this alteration in the shape of the lens, known as accommodation, light rays are focussed accurately on the retina. Because in middle age the lens loses some of its elasticity, accommodation is impaired, and glasses become necessary for reading. It should be realised that the muscles for accommodation, the ciliary muscles, are constantly at work during near vision. This is liable to produce a sense of strain in the eye and frequent periods of rest may be necessary when fine work is being done.

In a camera a diaphragm is provided for the purpose of cutting off the light rays which fall on the periphery of the lens, and also for regulating the amount of light admitted into the camera. In the human eye these functions are performed by the iris. This is a thin pigmented membrane, containing unstriped muscle fibre, which is suspended in

front of the lens. Always blue at birth, the iris later acquires different colours according to the amount of pigment deposited in it. In a dim light the pupil dilates and in a bright one it contracts. This is known as the pupil reflex, and the centre through which it takes place is situated in the midbrain. Belladonna paralyses the nerve endings in the iris and causes pupil dilatation. When an oculist wants to obtain a good view of the back of the eye he generally instils into it a few drops of belladonna or atropine, in order to dilate the pupil. Although the pupil reflex is usually initiated by the amount of light falling on the eye, movements of the iris are also provoked by psychological states. Fear, for instance, causes it to dilate.

The loss of elasticity of the lens which results from age is not the only reason for wearing glasses. Sometimes the fault in focussing lies not in the lens but in an abnormal shortness or length of the eyeball. Myopia, or short-sightedness, is a condition in which, owing to the lengthening of the eyeball, the focus to which light rays are brought falls in front of the retina. A lengthening of the eyeball may be caused by weakness of its coats (as a result perhaps of malnutrition) and it is likely to cause trouble when excessive efforts to accommodate are made, as when reading in a bad light. The error is corrected by diminishing the refractive power of the lens by the interposition of glasses which cause the light rays to diverge before entering the eyeball. A short-sighted person should, therefore, wear glasses with concave lenses. The reverse condition of hypermetropia, or long-sightedness, is due to a shortening of the eyeball. In this case the light rays are brought to a focus behind the retina. This type of error is corrected by causing the light rays to converge by the use of convex lenses. The common ocular error known as astigmatism is due to faults in the curvature of the cornea. As a result of these faults the individual, when

he looks at a series of radiating lines, sees some of the lines sharply focussed, whilst others are blurred because they are focussed either in front of, or behind, the retina. This error in the curvature of the cornea is corrected by wearing appropriate cylindrical glasses.

The retina, or innermost coat of the eyeball, is developed from the brain. At an early stage in the embryo's development two buds grow out from the mid-brain to form the optic nerves and the inner sensitive coats of the eyes. When the retina is examined microscopically it is found to be composed of three layers of neurones. The dendrons of the cells of the outermost layer (lying next to the choroid) have undergone a special modification so as to form what are known as rods and cones. These specialised retinal structures are sensitive to light and in them are initiated the nervous impulses which pass by the optic nerve to the brain. Where the optic nerve joins the retina no rods and cones are present, and this is known as the blind spot of the eye. In contrast to this there exists a small area of the retina (the yellow spot) in which rods and cones are particularly numerous. Vision here is specially acute, and when we want to see anything distinctly, such as the letters in a book, we instinctively turn our eyes in such a way that light falls on the yellow spot.

The impact of light on the retina produces changes in the sensitive nerve endings, and an impulse thence to the brain. A special pigment known as visual purple is present in the outer portions of the rods. This pigment is bleached when it is exposed to light, and regains its colour in the dark. Although it is doubtful whether visual purple is needed for daylight vision, it is of great importance for vision in dull lights. Shortage of visual purple accounts for the night blindness that is a characteristic of vitamin A deficiency (see page 53). Different individuals have different capacities

for seeing in poor light, depending probably on their supply of visual purple. It has been found that light produces two other changes in the retina. When it is illuminated the cones in the retina shorten; in darkness they lengthen. There are also present in the retina a number of pigment cells. When light falls on the retina the pigment granules within these cells flow into the processes that extend from them into the spaces between the outer parts of the rods and cones. Their probable function is to protect the rods and cones from too intense illumination.

The retinal nerve impulses pass along the optic nerve to the mid-brain and by relay fibres to the occipital (back) area of the cerebral hemispheres. It is in this region that the impulses are appreciated as images, and the images stored as visual memories. Damage to the occipital region causes blindness as effectively as damage to the eyes themselves. Indeed, destruction of the visual area of the brain brings about a disability that is greater than that resulting from destruction of the eyes. Blindness due to disease of the eyes leaves a man with some power of orientation, for he still retains visual memories by means of which he may be able to find his way about. If both occipital lobes are destroyed, this faculty is also lost.

The muscles that move the eye are controlled by centres situated in the mid-brain. It is by the synchronisation of these movements of the two eyeballs that we are able to combine the images from the two eyes into one. When the harmony of movement of the eyes is disturbed we see double. This can be demonstrated by means of a simple experiment. If while looking with both eyes at an object we press one of the eyeballs out of its position, double vision immediately results. Double vision may also complicate a bad squint, but fortunately this disability disappears in time by the forcible suppression of one of the

images. A temporary diplopia (double vision) is also produced by alcohol. The floating spots seen in front of the eye, and by many people regarded as a symptom of disordered liver, are caused by tiny opacities in the fluid content of the eye.

Hearing

The essential portion of the ear, that is, the middle and inner ear, consists of two parts, the sound-conducting organ and the sound-receiving organ. A noise is a vibration of air, and the vibrations may be of different wave-lengths and frequencies; the greater the number of waves per second, the higher is the pitch of the sound. When the vibrations fall upon any object they cause it to vibrate also. The object on which the vibrations fall in the ear is the drum, or membrana tympani. The function of the fleshy lobe of the ear is merely to collect vibrations and concentrate them on the ear-drum. This is a somewhat trumpet-shaped membrane unevenly stretched across the entrance to the middle ear. As a consequence of this uneven stretching the ear-drum is capable of vibrating to a large range of tones; according to Yearsley, to more than seven octaves of tones. The precise range differs in different individuals, some being unable to hear the high-pitched cry of a bat or sounds of very low pitch.

The middle and internal ear lie within the temporal bone of the skull. The vibrations of the drum are transmitted across the middle ear by a chain of tiny bones called the auditory ossicles. These are three in number, and are named the malleus (hammer), the incus (anvil) and the stapes (stirrup). The first of these bones is fixed to the drum and the last to a membrane stretched across an oval window which is the beginning of the inner ear. The vibrations of the drums are therefore transmitted by the ossicles to this membrane in the inner ear.

The receiving organ is housed in a coiled bony tube which, because of its resemblance to a snail, is called the cochlea (see Fig. 31). This contains a sensitive membrane strung across it like the wires of a harp. Since the coiled tube of the cochlea tapers, the membranes stretched across it are of different lengths, just as are the strings of the harp. The longer strands of the membrane vibrate to sounds of lower pitch, the shorter to sounds of higher pitch. What happens when sounds enter the ear is as follows. The ear-drum vibrates and the vibrations are transmitted across the middle ear by the chain of ossicles. This sets in motion the membrane stretched across the oval window and thus transmits the vibrations to the cochlea. Different areas in the cochlea respond to varying pitches of sound resounding within it, and this produces nerve impulses in the terminations of the auditory nerve. These nerve impulses are conveyed to the cerebral cortex, where they are registered as sound patterns. But if this sounding apparatus is to work efficiently the air pressure on the two sides of the drum must be the same, otherwise it will not vibrate. To ensure that this is so, there is a special canal which connects the cavity of the middle ear with the throat, a canal that is known as the Eustachian tube. Unfortunately this arrangement brings with it certain dangers, since catarrhal conditions of the throat may easily spread along the Eustachian tube to the ear. If this happens repeatedly, thickening of the ear-drum and of the ossicles may result, causing permanent deafness. Temporary deafness may be due to the pressure on the two sides of the ear-drum being unequal. Aviators returning to

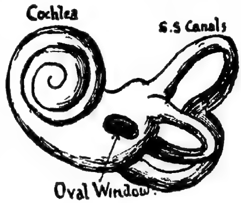


FIG. 31.—The internal ear, showing the bony cochlea and semicircular canals.

ground level from a great height sometimes complain of ear symptoms which can be remedied by swallowing movements. Swallowing opens up the tubes and thus equalises the air pressure on the two sides of the ear-drum.

The inner ear, as well as containing the cochlea, houses the three semicircular canals. By the help of these we establish our position in space. The three canals are so placed that each is at right angles to the other (see Fig. 31). Like the cochlea the canals contain within them a sensitive membrane on which are placed specialised nerve endings. When the body is in an abnormal position the nerve endings in one set of canals are stimulated and there is an immediate effort to restore the body to a normal position. This automatic effort is termed the 'righting reflex'. Sea-sickness may be caused by the violent movements imparted by the ship's motion to the fluid with which the semicircular canals are filled. This results in over-stimulation of the nerve endings, confusion and dizziness. Complete destruction of the canals deprives animals of all sense of balance. The symptoms are very similar to those caused by damage of the cerebellum.

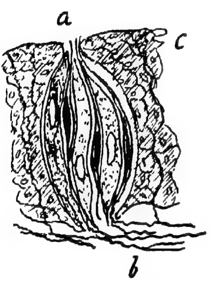


FIG. 32.—A taste bud. *a*, opening on the surface. *b*, nerve fibrils supplying bud. *c*, tongue epithelium. (After Merkel Henle.)

Taste and Smell

These two special senses will be described together because they are closely allied. Whilst the nerve endings in the eye and in the ear are stimulated by movements in the form of vibrations, those in the nose and palate are stimu-

lated by chemical changes. For this reason taste and smell are sometimes called the chemical senses. The specialised end-organs of taste are the taste buds (see Fig. 32). These spindle-shaped collections of cells are found in the mucous membrane of the tongue, especially on its tip, its edges and the posterior third of it. The deeper ends of the taste cells are surrounded by the terminal filaments of the gustatory or taste nerves. If a substance is to be tasted it is essential that it should be in solution, and all insoluble matter, like chalk, is without taste. Different parts of the tongue are sensitive to different varieties of taste; for example, sweetness is best appreciated towards the tip, and bitterness towards the back of the tongue. Wine experts and tea-tasters are aware of this and employ different parts of the tongue for sampling their wares.

The sense of smell is the most mysterious of all the special senses and the one about which we know least. It is very readily fatigued, and when this happens its fatigue is specific. By this is meant that the olfactory mucous membrane of the nose becomes quite insensitive to one kind of smell but remains sensitive to another newly introduced. Taste and smell are so closely allied that many so-called tastes are in reality odours. It has been asserted that if an onion be chewed with the eyes closed and the nose blocked it is difficult to distinguish it from a strawberry. Unfortunately at the time of writing this book it is impossible to verify whether this is the case or not. An epicure in old brandy uses a special glass in order that he may enjoy to the utmost the delicate aroma and taste the brandy as fully as possible. The olfactory cells (the specialised cells of smell) are situated in the mucosa of the nose. Nerve fibres from them perforate the bone separating the nasal cavity from the interior of the skull, and reach the olfactory region of the brain. Because the stimulus for the olfactory cells is in a

gaseous state, the sense of smell is to a great extent lost if we have a cold. At such a time the swollen state of the mucous membrane prevents the odorous gases from reaching the olfactory cells. A temporary loss of smell may be produced by a local application of cocaine. So sensitive are the olfactory cells that, according to calculation, they can sense the gas given off from a 300-millionth part of a grain of musk. It is interesting to think that a twenty-year-old Harris tweed coat still gives off particles which can be detected by the nose. And compared with the dog, smell in the human being is a blunted sense.

Cutaneous Sensations

The skin is capable of appreciating four kinds of sensations; heat, cold, touch and pain. The ability to register the first three of these sensations is indeed limited to the skin. There is no tactile sense in the deeper parts of the body, and we are unable to appreciate the fact that the lungs are slipping over the inner surface of the chest, or that the stomach is in contact with the intestines. In these organs we can only appreciate pain, and, in certain parts of the alimentary canal, the difference between heat and cold.

The four different cutaneous sensations of heat, cold, touch and pain are distributed in a patchy and irregular manner over the surface of the skin. If the skin be touched with a stiff bristle, spots will be found on it where the impact of the bristle cannot be felt. A similar experiment with a fine metal rod capable of being heated reveals the existence of other areas that are insensitive to changes in temperature. The fact that different nerve fibres in the skin carry different sensations is corroborated by other observations. There is a disease known as syringomyelia in which the patient retains the sense of touch but loses appreciation of heat and pain. As a result he frequently burns or other-

wise injures himself. For physical pain is of practical utility; it is the signal that all is not well with some part of our body. We have all experienced the sensation of a limb 'going to sleep'. When this happens touch and sensitiveness to cold are lost in the limb, but the capacity to appreciate heat remains.

The nerve fibres carrying tactile impulses are provided with several types of special end-organs. The best known are the Paccinian corpuscles (see Fig. 33). These tiny oval bodies are situated in the deeper layers of the skin. The acuteness of tactile sensations may be measured by means of a pair of compasses. The smaller the distance between the two points which can be appreciated as separate sensations, the more acute is the sense of touch. When tested in this manner the sensitivity of the tip of the tongue and of the index finger is about the same, namely, one millimetre. The sensitivity of the palm is eight millimetres and that of the neck sixty-seven millimetres. It is with the tips of the fingers that Braille writing can best be appreciated.

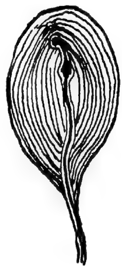


FIG. 33.—One variety of touch organ in the skin. (Paccinian corpuscle.)

In addition to this sensitivity of the surface of the body there is also a sensitivity of its depth. We are all able to appreciate to some extent the position of our limbs and can lay our hands on some object in a dark room if we remember its position in space. This sense of position of the limbs is also of great importance in learning new movements, such as the movements for playing tennis. It depends on our muscles and tendons being supplied with special nerves that are quite independent of those that stimulate the muscles into activity. In the

disease known as locomotor ataxia the sense of the position of the limbs is lost owing to degeneration of these special nerve fibres. Unless he looks at his legs, a tabetic patient is unable to walk. Sometimes the earliest warning that the patient receives that something is wrong is his tendency to fall when he shuts his eyes.

In addition to the special senses that have been described there are also a number of vaguer sensations arising from the viscera. Hunger is an example of such a sensation. It is probably due to contractions in the stomach. Thirst is another example. This is a feeling provoked by dryness of the mouth, tongue and throat, resulting from an insufficiency of saliva. Other impressions less easily described reach the brain from different parts of the body even though we are not generally conscious of them. In certain neurotic states a patient becomes conscious of sensations that are normally suppressed. Sometimes these sensations occasion him great distress. It must be remembered that in such a patient the threshold of pain is diminished, and what another person might not notice, to him is acute agony. The less attention that is paid to the automatic working of the body the better it is for us.

There is an old belief that at one time man was conscious of all the workings of his body. It was decided, however, that it would be better if these became automatic and unconscious so that he might devote his attention to higher things. The authenticity of this story may be doubted, but the moral that it contains is excellent.

CHAPTER X

CHEMICAL MESSENGERS

IT has been seen that the central nervous system controls and correlates the manifold activities of the body. But all organisms do not possess a nervous system, and yet their activities are harmonised. It is obvious, therefore, that the central nervous system cannot be the only method of co-ordination. We know that there is also a chemical method of co-ordination exercised through the agency of the 'hormones', or chemical messengers. The word 'hormone' was first used by Bayliss and Starling who, over thirty years ago, discovered that a flow of pancreatic juice took place after a meal, even though all the nerve supply to the pancreas had been severed. Clearly the stimulus to the pancreas must have been carried to it in the blood stream. Later they proved that this stimulus was a special secretion formed in the duodenum and passing thence by the blood to the pancreas. Later they succeeded in extracting a substance from the mucous membrane of the duodenum which by injecting it into the blood stream stimulated the pancreas. They gave the name of secretin to the substance and stated that it was one of many hormones, or chemical messengers, formed by the body. Chemical stimulation of the pancreas occurs naturally during digestion; the acid chyle provokes the formation of secretin in the duodenum, this is absorbed into the blood stream and in turn stimulates the pancreas. A great number of other instances of hormone action in the body have since been discovered. The organs that possess in a high degree the ability to form hormones are the endocrine organs, or glands of internal secretion.

Few ideas in physiology are entirely new, and the idea of control by hormones, although it dates from the beginning of the present century, is a resuscitation and elaboration of an idea which was widely held in the Middle Ages. Old physiologists regarded the body as being controlled by four 'humours', and illness was believed to be due to an upset in their balance. The four cardinal fluids of the body, according to this view, were blood, phlegm, yellow and black bile, which were correlated with the four alchemical elements, fire, earth, air and water. Ancient Chinese medicine differed from ancient European medicine in this matter only in postulating five primordial substances, the seat of which lay in what the Chinese regarded as the five chief organs, the spleen, liver, heart, lungs and kidneys. Treatment in the Middle Ages was based on the idea of restoring the balance of the humours. As an example may be cited the idea that an overdose of the sanguine humour could be corrected by bleeding. Later, Bordeu, a physician at the Court of Louis XV, came much nearer the truth. Instead of holding the view that the body formed only five humours, or secretions, he stated that each organ of the body was 'the workshop of a specific substance that passes into the blood'. He believed that if any of these substances were absent the harmony and poise of the body suffered. This guess of Bordeu has since been proved to be correct. The various secretions of the endocrine glands maintain a balance, which, when it is upset, gives rise to definite symptoms. In this chapter the endocrine glands and their secretions will be described.

The Thyroid Gland

The thyroid, composed of two lobes, lies on each side of the trachea just below the larynx (Adam's apple). It is highly vascular and, like other glands, is supplied with fibres from

the sympathetic system. Attention was drawn forcibly to the thyroid in the latter part of the last century. Until then it had always been regarded as an organ of no great importance, which could, if necessary, be dispensed with. Two Swiss surgeons, emboldened by the progress that had been made in antiseptic surgery, undertook removal of the entire gland in certain cases of goitre. The operation was a success, but to their consternation the patients developed strange symptoms and changes that converted them into cretins. Not only did their bodies suffer, the skin becoming wrinkled and dry, the features coarsened and the fingers thickened, but the temperament of the patients also altered. They became apathetic and dull-witted, lost all initiative and developed a guttural speech. It was obvious that they had been deprived of something that was as essential to the health of their minds as it was to that of their bodies. Removal experiments on animals produced similar changes. What was of extreme importance was the later discovery that these changes could be corrected by feeding the animals on dried thyroid gland.

Eventually chemists succeeded in isolating from the gland its active principle. This was proved to be an organic compound containing a large amount of iodine. Human beings that were deficient in thyroid responded equally well to the treatment.

The signs of thyroid deficiency are now well known. Complete absence of the gland produces a condition which is known as myxoedema. This, as its name implies, consists in a general swelling of the body, the face becoming puffy, the hands spade-like and the skin dry and wrinkled like that of the aged. The scalp is scurfy, the hair tends to fall out and the outer half of the eyebrows to become thin. There is a general fall in the activity of the body and a slowing of the body chemistry, associated with a diminution in the

frequency of the heart-beat. Arrest of development of the thyroid at an early age results in cretinism. Growth stops, and this stunting of the body is linked with a corresponding backwardness of mental and sexual development. When a cretin is fed upon thyroid gland, or given thyroid extract, his condition improves. Nowadays thyroid is sometimes given to children to encourage growth even when they show no signs of cretinism. That the gland has an effect on growth is shown by the fact that the addition of thyroid extract to an aquarium hastens the metamorphosis of tadpoles into frogs.

Sometimes, instead of being under-developed, the thyroid enlarges, with a consequent increase of its secretion. In this case an entirely different set of signs and symptoms is produced. There is an increased activity of the body metabolism, associated with a quickened pulse. The patient becomes over-active, anxious, emotional and tremulous. These symptoms occur in cases of exophthalmic goitre, a disease characterised by a swelling in the region of the thyroid associated with prominent staring eyes. That this trouble is due to an excess of thyroid secretion is proved by the fact that it is relieved by the surgical extirpation of part of the gland. Removal of the entire thyroid would produce the reverse condition of myxoedema, so sufficient must always be left for the normal requirements of the body. Hyperthyroidism (an excess of thyroid secretion) is especially apt to occur in women during puberty, pregnancy and lactation. In many countries, for example, in Switzerland, goitre was, until recently, an endemic disease. Psychic states, particularly anxiety and excitement, stimulate the action of the thyroid, and many cases of exophthalmic goitre follow after a period of excessive emotional disturbance.

The Suprarenal or Adrenal Glands

These are two small yellow glands lying just above the kidney. The suggestion that they might form an internal secretion was first made in 1881 by Dr. Addison, a Guy's Hospital physician. He found that certain cases of wasting, with progressive muscular weakness and bronzing of the skin, were associated with tuberculosis of these bodies. The disease received his name and is still referred to by it. It was later shown that the suprarenal glands were composed of two parts, a cortical, or outer layer, and a central, or medullary portion. In fish the two parts remain separate, and it is possible to remove one portion without injury to the other. This experiment has been helpful in elucidating the function of the gland. Early experiments had shown that the removal of the whole gland was rapidly fatal, but it was now shown that the medullary portion could be excised without causing death. Embryological studies also throw light on the subject. It has been found that the medulla develops from the same structures that gave rise to the sympathetic system, and the cortical part from those from which the reproductive organs are developed. From the medulla has been obtained an extract (adrenaline) which has the effect of constricting blood vessels. Adrenaline is now used for the purpose of diminishing the vascularity of tissues and is often applied to the mucous membrane of the nose in order to reduce bleeding during operations. When injected into the blood stream, adrenaline produces the same general effects as does stimulation of the sympathetic system; the circular muscles in the coats of the blood vessels contract and the blood pressure rises. Adrenaline has the reverse effect on many of the muscles of the viscera, causing relaxing of the musculature of the stomach, intestines, urinary bladder and the bronchial tubes. What is equally interesting is that the stimulation of the sympathetic nerve fibres which supply

the suprarenal glands causes an increased flow of adrenaline into the blood stream. Cannon found that certain psychological conditions, such as rage, anxiety and fear, caused the amount of adrenaline in the blood to be increased. He regards this flooding of the system with adrenaline as being responsible for many of the changes that occur in an animal under the influence of fear or rage, the erection of the hair and dilatation of pupils, and in man the blanching of the skin from constriction of its capillaries. From his observations and deductions has arisen the 'emergency theory' of adrenal activity. Any emergency provoking fear or anger causes the adrenals to throw into the blood an excess of secretion and thus to mobilise the body for the activities that are necessary to meet that emergency, whether they be flight or fight. The suprarenals are consequently often referred to as the emergency glands of the body. Whilst the action of these glands is purposive and helpful, it should be realised that in certain circumstances the results of their activities might prove harmful. A state of chronic fear or anxiety leads to a prolonged excess of adrenaline in the blood, causing a prolonged rise in the blood pressure. The body has been mobilised for action, but remains inactive. Excessive anxiety concerning real and unreal dangers is one of the scourges of modern life. Indeed some degree of anxiety is the constant state of most people, even when they do not realise it. It is not surprising that vascular troubles are increasing and that in the United States (where the tempo of life is probably highest) deaths from heart lesions are only exceeded by those from cancer.

We know less concerning the functions of the cortical than about those of the medullary part of the suprarenal bodies. There are, however, reasons for believing that the cortex produces a substance which neutralises the poisonous products of nitrogenous metabolism. It is also known that

increased activity of the cortex accentuates masculine sex traits both in young males and in young females. If a girl develops a growth in the adrenal cortex she loses many of her feminine characteristics and tends to develop those of the male. Her breasts diminish in size, she develops hair on the face, and her voice becomes more like that of the male. A successful surgical removal of the cortical tumour causes the disappearance of these abnormalities. Recent observations have also suggested that the state of debility which follows many diseases, such as influenza, may be due to exhaustion of the adrenal cortex, and efforts are now being made to treat debility by means of extracts of the suprarenal cortex.

The Pituitary Body

The pituitary is the most important of all the ductless glands in the body, not only because it forms a great number of internal secretions, but also because it exercises control over the other endocrine glands. It may truly be called the leader of the endocrines. It is situated at the base of the brain, lying in a deep depression in the skull. Connected with the brain by a stalk, it receives from this structure nerve fibres which are of great interest to both physiologists and psychologists. The pituitary is made up of two lobes, anterior and posterior, discharging different functions.

The anterior lobe of the pituitary is larger than the posterior. Its removal in young animals has a profound influence on their growth; the formation of bone tissues is arrested, no more teeth are erupted and sexual and mental development cease. In other words, removal of the anterior lobe produces dwarfism. The reverse conditon, namely, increased activity of the anterior lobe, results in giantism. Sometimes the giantism is local, affecting only the head and the hands and feet, and not the trunk and limbs. This condition is

known as acromegaly. It is characterised by an increase in the size of the skull, a marked overgrowth of the frontal bones and supra-orbital ridges, and an over-development of the jaw. The facial appearance of an individual suffering from acromegaly resembles somewhat that of the stone figures found on Easter Island, and it has been suggested that the original inhabitants of that island may have suffered from this disease. Increased activity of the anterior pituitary early in life results in the whole body being affected, and if young rats be fed with this part of the gland their growth is markedly stimulated. This is the diet that H. G. Wells imagined long ago when he wrote *The Food of the Gods.* In addition to stimulating growth the anterior pituitary controls the development of many of the other endocrine glands, notably that of the thyroid and of the sex glands. Anterior lobe deficiency leads to under-development of the reproductive system. It also has a profound influence on the carbohydrate metabolism of the body. The anterior pituitary is regarded as being responsible for a great many functions and it is difficult to understand how so many secretions can be formed within a structure that is no bigger than a large pea. This has led to the suggestion that it works as an activator of the other glands, producing its effects indirectly rather than directly.

Extirpation of the posterior lobe of the pituitary does not cause any profound disturbance in the body. From it have been derived two different extracts, one causing a contraction of smooth muscles (particularly of the blood vessels and uterus) and the other having a marked diuretic effect (increased output of urine). Use is made of the first of these two active principles in labour. When the contractions of the uterus are too feeble to be effectual, an injection of posterior pituitary is sometimes given in order to increase their strength.

One of the interesting points about the pituitary is its situation. It is the only endocrine gland (except for the apparently unimportant pineal) which is intimately associated with the brain, and, what is of great importance, with that part of the brain that we now believe to be related to the emotional life (the thalamus). By virtue of its close connection with that structure the pituitary is influenced by the thalamus, and the thalamus by the pituitary. This area at the base of the brain may therefore be regarded as a meeting-ground of chemical secretions and nervous impulses, and to those who are interested in the relationship between mind and body it is of great importance.

The Sex Glands

These are often referred to as the gonads. The action of the internal secretions of the sex glands on the body has long been known, for castration is one of the oldest operations performed by man. By means of this operation he has converted the bull into the placid ox, the cockerel into the capon, and the virile bearded man into the fat, hairless, sexless eunuch. By the removal of the testes the services of the choristers were at one time retained in the Papal Choir long after the age at which the boyish voice would normally break. It is only if castration is performed early in life that all these changes are produced. Removal of the testicles in adult life has less effect, since the body has already reached its full development. The main function of the internal secretion of the testes and of the ovaries is the development in the body and mind of the distinctive characters appertaining to each sex. When the gonads are removed at an early age the secondary sex characteristics remain in abeyance. That this is due to the absence of an internal secretion is shown by the fact that normal development is resumed if fragments of the appropriate gonads be grafted on to the

body. What is still more interesting is the observation that, by using grafts of the opposite sex, the development of the body can be pushed in the opposite direction. Steinach grafted young male castrates with ovary and young female castrates with testis, and produced male adults with many of the characteristics of females, and females with many of those of males. This action of the sex secretions on the body accounts for the interesting phenomenon of sex reversal. Occasionally it happens that a fowl which started life as a hen becomes a cock. On dissecting such an animal it is found that the ovaries maintaining its henship have been destroyed by tuberculosis and that a rudimentary testis within it has developed and converted it into a cock.

Although the secretions of the testes and ovaries are specific, that is, one makes for maleness and the other for femaleness, both may be found in the body of the male and of the female. This being so, it is not surprising that various forms of intersexuality are found. We all recognise that in addition to the masculine male and the feminine female there exist effeminate men and masculine women. In certain cases this blending of the two sexes is so marked as to be pathological. There have even been individuals of whom it is difficult to say whether they were truly male or truly female.

There remain to be described three other endocrine glands, the functions of which are less well understood. These are the pineal, the parathyroids and the thymus.

The pineal gland in man is a small solid organ, half the size of the pituitary, which projects from the roof and hind part of the brain. Descartes looked upon it as being the seat of the soul, but modern physiologists attach but little importance to it. Great mental and sexual precocity have sometimes been observed in boys whose pineal glands had been destroyed by tumour. For this reason it has been

supposed that it provides a secretion which acts as a brake on sexual development. Another view is that the pineal body in man is a relic of a third eye which is found in the mid-line of the skull in certain lizards.

Extirpation of the parathyroids in animals causes death. They are quadruple glands that lie alongside the trachea, covered by the lateral lobe of the thyroid. The parathyroids appear to exercise two effects, one on calcium metabolism and the other on the central nervous system. Disease of them is followed by the appearance of tremors and muscular spasms, a condition that is known as tetany.

The thymus is situated in the chest behind the upper part of the breast bone, or sternum. Very little is known with certainty about its function, but it is generally agreed that it is more developed in the child and undergoes regression at puberty. When the thymus is enlarged it may be a cause of death under an anaesthetic, the condition being known as 'status lymphaticus'. Injections of thymus have given only dubious results.

Two additional glands must be considered, although they cannot be included under the term ductless glands. These two organs are the pancreas and the spleen.

The Pancreas

As well as providing a digestive juice the pancreas forms an internal secretion that exercises a powerful influence over carbohydrate metabolism. This internal secretion is formed by collections of cells interspersed between the pancreatic tubules. If the pancreas be removed from a healthy dog, the animal develops hyperglycaemia (excess of blood sugar), accompanied by glycosuria (sugar in the urine). The latter disappears if a piece of pancreas be successively grafted on to the animal. Diabetes is very closely related to this form of pancreatic glycosuria. In this

disease a large amount of sugar is excreted in the urine, even although carbohydrates have been eliminated from the diet. This sugar is derived from the breaking-down of body tissues, and more particularly of body proteins. Consequently severe diabetes is associated with loss of weight. For a long time attempts to treat diabetes by means of extracts of pancreas failed. The great discovery made by Banting and his colleagues was that a more effective extract could be obtained from the pancreas by first ligaturing its duct. The ligature put out of action the external excretory function of the gland, namely, the production of pancreatic juice. As a consequence the function of internal secretion increases and a more powerful and purer extract is obtainable. This extract, known as insulin, when administered hypodermically to a rabbit produces hypoglycaemia (a fall in blood sugar) which can be remedied by giving sugar by the mouth. The modern treatment of diabetes consists in regulating the amount of carbohydrate in the diet and, when necessary, making good the deficiency of pancreatic internal secretion by injections of insulin.

The Spleen

This organ is usually included amongst the glands but it does not rightly belong to their company, for no internal secretion has yet been extracted from it. Individuals are occasionally born without a spleen and it can be removed without causing any ill effects. The spleen lies on the left side of the abdomen under cover of the lower ribs. It consists mainly of fibrous and elastic tissue, muscle fibre, blood vessels and lymphoid tissue (tissue similar to that found in the lymphatic glands). It would seem that the spleen discharges several functions. Because it is highly vascular it may act as a reservoir for blood in the same way that the liver serves as a reservoir for the portal circulation.

It also plays a part in the life-history of red blood corpuscles, new corpuscles being formed in it and old ones being deposited in it. The iron from these broken-down blood corpuscles is stored in the spleen as well as in the liver. It is possible that it performs similar functions in the case of the white corpuscles, for in leukaemia (a disease characterised by an enormous increase in the number of leucocytes) the spleen is markedly enlarged. Because it contains much muscle fibre it can contract, and its rhythmic contractions may assist the circulation of the blood.

There are also reasons for believing that the spleen takes part in the defence of the body against bacterial infection. When micro-organisms and their poisons are circulating in the blood (for example, in typhoid fever), the spleen generally enlarges. A swollen spleen is also characteristic of chronic malaria, and in the old days of negro slavery accidents sometimes resulted from this enlargement. A brutal blow to a slave has been known to cause rupture of an enlarged spleen, followed by death from internal haemorrhage. In still older days it was thought that the spleen was connected with anger and bad temper, so much so, indeed, that the word has become synonymous with these unpleasant emotions. It is possible that the irritability associated with chronic toxaemia and enlargement of the spleen may have been responsible for this idea. This is not unlikely, since in Elizabethan times malaria (the ague) was a comparatively common complaint in England.

CHAPTER XI

REPRODUCTION

ONE of the features which distinguishes animate from inanimate bodies is the power of reproduction. In low organisms like the amoeba this is a very simple affair; the organism merely divides into two. This multiplication by fission is not confined to unicellular organisms, for it occurs also in many sea-anemones and worms. In the more highly organised forms of life special cells, the germinal epithelium, are set aside early in life for the purposes of reproduction. From the germinal epithelium are eventually formed the testes and the ovaries. In most animals the union of two distinct cells, one from the male and one from the female, is necessary for the formation of new life. Usually these come from two different individuals, but there are plentiful examples in the animal and vegetable worlds of the two cells being formed by the same individuals. In this book only human reproduction will be considered.

The Male Reproductive System

This consists of the testes (which produce the male cells, or spermatozoa), the accessory sexual glands (the epididymes, prostate and the seminal vesicles) and the various channels and passages along which the spermatozoa pass (the epididymal canal, vas deferens, ejaculatory ducts and urethra).

The testicles are ovoid bodies suspended by means of the spermatic cords within the scrotum. They are covered by a thick capsule, known as the tunica albuginea, and if split open are found to consist of a great number of finely coiled

tubes (the seminiferous tubules). Examination of the seminiferous tubules under a microscope reveals the fact that they are made up of several layers of highly specialised epithelial cells which, by a complex process of cell divisions, give rise to the male germ cells, or spermatozoa. A human spermatozoon (see Fig. 34) resembles a tadpole, and consists of a head, middle piece and tail. The head contains the nucleus and varies greatly in size and in shape in different animals. In man it is a flattened oval appearing somewhat pointed when seen in profile. The tail is actively motile and by strong lashing movements propels the spermatozoa through the fluid in which it is suspended. The number of spermatozoa produced by the two testes is enormous and three hundred million may be discharged at a single ejaculation.

FIG. 34. — The male germ cell, or spermatozoon. *H*, head, containing the nucleus. *M*, middle piece. *T*, the actively motile tail by means of which it propels itself.

It will now be necessary to describe the complicated system of channels through which the spermatozoa must pass in order to reach the urethra. The seminiferous tubules converge towards one side of the testis, where they open into a dense network of channels known as the rete testis. From this network emerge twelve to fifteen ducts which finally unite to form a single closely coiled tube, the epididymal canal (see Fig. 35). This, enclosed in its capsule and closely applied to the side of the testis, constitutes the epididymis. The calibre of the epididymal canal is about the same as that of coarse thread, and it is not surprising that after an attack of epididymitis, or inflammation of the epididymis (a common complication of gonorrhoea), its lumen becomes occluded. Should this happen on both sides no spermatozoa can emerge and the man is sterile.

The coiled epididymal canal widens out into a larger channel, the vas deferens. This thick muscular duct, together with the arteries, veins and nerves in the spermatic cord, passes out of the scrotum into the abdomen to reach the base of the bladder and the prostate gland. Here the vas deferens terminates in the ejaculatory duct, which by piercing the prostate reaches the posterior part of the urethra

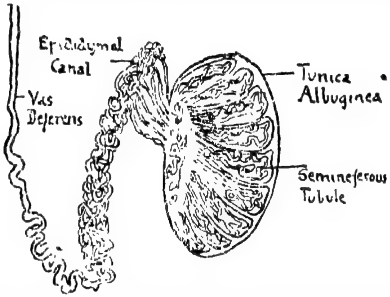


FIG. 35.—Diagram showing seminiferous tubules and epididymal canal

(see Fig. 36). During coitus (the sexual act) large numbers of spermatozoa are propelled along the vas by the peristaltic movements towards the posterior urethra. There the spermatozoa become mixed with the secretions of the accessory sexual glands (the prostate and the seminal vesicles).

The function of the prostate and of the vesicles is to provide a secretion in which the spermatozoa can live. It is probable that the glandular cells lining the epididymal canal serve the same purpose. The prostate is a glandular structure shaped like a chestnut and situated at the base of the bladder. It is perforated by three channels, the urethra, or bladder outlet, and the two ejaculatory ducts. In middle and in old age the prostate may enlarge and cause micturi-

tion troubles. So far as is known, it does not manufacture any internal secretion and is solely concerned with fertility. The two seminal vesicles lie just above it, their ducts joining with those from the testicle (vas deferens) to form the ejaculatory duct. The term seminal vesicle is a misnomer; it is not a receptacle for semen, but a glandular structure that contributes a secretion to the semen.

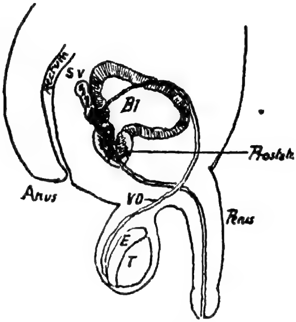


FIG. 36 — Male reproductive system. *Bl.*, bladder. *S V*, seminal vesicle. *VD*, vas deferens. This duct passes by the side of the bladder and not, as might appear in the diagram, through it. *E*, epididymis. *T*, testis.

The penis, or phallus, is the male organ by which the semen is deposited in the female genital passages. It is composed of erectile tissue surrounded by a strong fibrous sheath. Erectile tissue is spongelike in character and erection is brought about by the filling of its spaces with blood, whereby the organ becomes larger and more rigid. The filling is produced both by an increase in the amount of arterial blood reaching the penis and by a reduced outflow from it, resulting from compression of its veins. Erection and ejaculation are controlled by two centres situated in the lower part of the spinal cord. Coitus is essentially a reflex act, although it is associated with complex psychical phenomena.

The Female Reproductive System

This consists of the ovaries, Fallopian tubes, uterus and vagina. The ovaries are oval bodies lying near the side wall of the pelvic girdle. They are formed of fibrous tissue, blood vessels, nerves and lymphatics, with an outer covering of epithelium. Within the substance of the ovary are islands of cells that are derived from the germinal epithelium, that is, from the cells which, at an early stage in the embryo's development, were set aside for the function of reproduction. These islands of cells, called Graafian follicles, contain the ova, or egg cells. The number of Graafian follicles in the ovaries of a newborn child has been estimated at seventy thousand, of which the vast majority never reach maturity. It is the work of each of the Graafian follicles to prepare an ovum, one of which will be liberated every month. This preparation is known as the maturing of a follicle. The more mature follicles usually lie deep in the ovary. Each month a ripened follicle advances towards the surface of the ovary, ruptures and ejects its ovum into the mouth of the Fallopian tube. After the mature follicle has ruptured, the cells lining it multiply and form large yellow masses. These collections of yellow pigmented cells in the ovary are called corpora lutea. Should pregnancy follow the discharge of the ovum, the corpus luteum of that month becomes much larger and produces an internal secretion which helps to bring about the development of the uterus during pregnancy.

The ovum or egg cell is a large spherical cell that may just be visible to the naked eye as a tiny speck. The time of its discharge from the follicle varies slightly in different people and in different cycles, but it is usually during the mid period between two successive menstruations. It is during this time, when a Graafian follicle is about to burst, that a woman is most fertile. If the ovum is not fertilised it perishes. Should, however, spermatozoa be present in the female passages, one

of them may succed in reaching the ovum and in fertilising it. This union of the male and female germ cells generally takes place within one of the Fallopian tubes. The Fallopian tubes are also called oviducts, since they convey the ova from the ovaries into the cavity of the womb, or uterus. They measure from four to five inches in length and are composed of muscle fibre lined with ciliated epithelium resembling that found in the bronchi. The currents set up by the cilia help to sweep the ovum in the direction of the uterus. Like the uterus itself, the tubes are enclosed by the peritoneum, or glistening membrane, which provides a covering for most of the viscera. The Fallopian tubes are not really continuous with the ovaries but widen out into trumpet-shaped openings that are in contact with them. The ova fall into these expansions and are conveyed from them to the uterus.

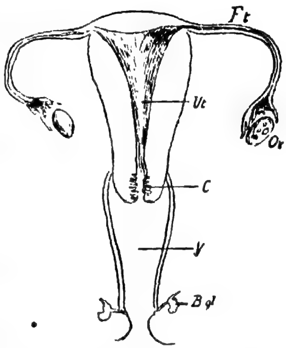


FIG. 37.—Female reproductive system. *Ut*, Uterus. *Ft*, Fallopian tube *Ov*, ovary, showing Graafian follicles, one of which has ruptured *C*, cervix. *V*, vagina. *B gl.*, Bartholin gland.

The uterus is a hollow, pear-shaped and highly muscular organ which appears somewhat flattened when viewed from the side (see Fig. 37). It measures one inch in thickness, three inches in length and, at its widest part, two inches in breadth. At each upper corner it is joined by a Fallopian tube, and below it ends in a neck, or cervix, which projects into the upper part of the vagina, or female genital passage. The uterus is lined with an epithelium that is particularly

rich in glands, and is known as the endometrium. The endometrium in a non-pregnant uterus undergoes a complex cycle of changes every month in preparation for a possible pregnancy. Particular attention must be paid to this function (menstruation). The endometrium is only at rest for a few days in every month and most of the time it is in a state of great activity. The cycle of changes which it undergoes may be divided into four: the stage of quiescence, the constructive stage, the destructive stage and the stage of repair. During the constructive stage the endometrium becomes greatly thickened, partly by cell division and partly by the engorgement of its glands and blood vessels. This period of thickening is followed by a destructive stage during which blood leaves the capillaries and extravasates (leaks) into the uterine tissues. A few days later the extravasated blood finds its way to the surface and, together with cast-off epithelium and other debris, appears as a discharge. As soon as the menstrual flow has ceased, the repair of the endometrium begins. Extravasated blood that remains is absorbed, dilated vessels contract, and the lining cells which have been lost are replaced by cell division. Out of the twenty-eight days constituting the normal menstrual cycle about five are taken up by pre-menstrual congestion, four by the flow, seven by the period of repair, and twelve in a state of comparative quiescence. Menstruation occurs only amongst human beings and the higher apes, although there is some similarity between it and the changes occurring during the rutting season of the lower animals.

The whole of this complicated cycle is controlled, not by the central nervous system, but by the internal secretions of the ovary and of the pituitary. The removal or disease of either of these glands causes its disappearance. The cessation of menstruation happens naturally at a certain period in a woman's life, usually between forty-five and fifty. This meno-

pause, or climacteric, is associated with a reduction in the size of the ovary and a disappearance of the Graafian follicles within it.

If the union of the spermatozoon and ovum takes place, in other words if the woman conceives, the extravasation of blood and degeneration of the endometrium is averted and the fertilised ovum becomes embedded in it. Pregnancy, therefore, is accompanied by a temporary cessation of menstruation. This does not mean that the disappearance of the menses is necessarily indicative of pregnancy. It is an interesting fact that although menstruation is under the control of the endocrine glands it may be affected by psychological disturbances. Fear of, or even a fervent desire for, pregnancy may sometimes result in a postponement of the menstrual flow. This is only one more example of the close interdependence that exists between the endocrine glands and the central nervous system, and of the intimate correlation between mind and body.

The cervix, or lowermost part of the uterus, is a highly glandular and at the same time highly muscular structure. It has great extensibility, a property that is necessary to it as, during labour, it must dilate sufficiently to allow the passage of the child. The vagina, or muscular passage that extends from the cervix to the surface of the body, is equally dilatable. The lining of this passage is thrown into many ridges and folds. Although it contains no glands, accessory sexual glands (such as Bartholin's glands) open into it. Because the secretions of these glands are acid they exert a strong bactericidal action and thus serve to guard the uterus from ascending infections.

Coitus and Fertilisation

As the result of the sexual act spermatozoa are deposited either on the cervix itself or in the upper part of the vagina.

By means of their own motility, aided possibly by the suction action of the uterus, these traverse the cervical canal and uterine cavity to reach the Fallopian tubes. How a spermatozoon contrives to find the egg cell is not clearly understood, but it is suggested that it is by means of chemotaxis (chemical

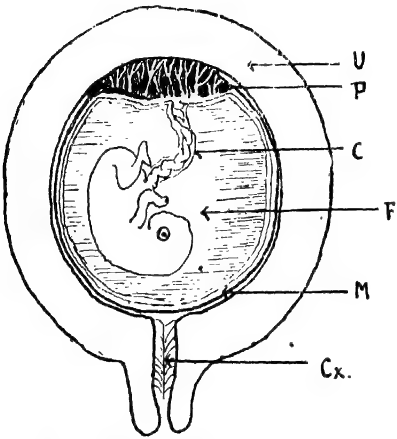


FIG. 38.—Diagram of foetus developing within the uterus. U, uterus. P, placenta C, cord. F, foetus surrounded by amniotic fluid. M, foetal membranes. Cx, cervical canal.

attraction). If the spermatozoon succeeds in fusing with the ovum, its tail—no longer necessary—is absorbed, whilst its nucleus unites with the nucleus of the ovum. A single nucleus is thus formed, half of the chromosomes of which have been derived from the mother and half from the father. The oosperm (the product of the fusion of the male and female cells) then undergoes cleavage, dividing first into two and each half again into two, etc. etc. The mass of cells thus

formed next burrows into the prepared lining of the uterus and henceforth receives its nourishment from it. It is the province of embryology to study the further development of this mass of cells, and in an elementary work on physiology a detailed description of the evolution of the foetus would be out of place. All that need be said is that the outer layers of the developing embryo eventually form special membranes and that it is partly from these and partly from the cells of the endometrium that the placenta is derived (see Fig. 38). This structure is the nutritive organ of the embryo, on one side of which flows the maternal blood and on the other, the blood of the foetus. Through the cells separating these two vascular systems an interchange of material takes place, food and oxygen being absorbed and waste products excreted.

Labour

When pregnancy has lasted two hundred and eighty days the uterine contractions, known as labour pains, begin. These initiate parturition, or the act of expelling the child from the uterus. Labour is divided into three stages. During the first stage there are rhythmic contractions in the walls of the uterus which cause the cervix to dilate. This dilatation is assisted by the projection into the cervical canal of a finger-like process of the membranes in which the child is enclosed. Actually the child lies in the fluid, known as the liquor amnii, which the membranes enclose. When the uterine contractions have become sufficiently strong the membranes burst and the liquor amnii escapes. The rupture of the membranes and the escape of fluid mark the end of the first stage of labour. During the second stage the head of the child is pressed first through the cervix and then through the vagina. In order to bring this about the contractions of the uterus become stronger, more prolonged and more frequent.

Assisted by strong contractions of the abdominal muscles, the child is forced through the dilated cervical canal and vagina and eventually expelled. The third stage of labour consists in the expulsion of the placenta and membranes. After dying down for twenty or thirty minutes, the uterine contractions are renewed and the placenta and membranes delivered. All these complicated movements of parturition are controlled by a special centre in the lower part of the cord. Exactly how this mechanism is brought into action at the end of gestation is not yet known. A variety of stimuli have been suggested as the provoking cause of parturition, such as distension of the uterus, accumulation of carbon dioxide in the blood, degenerative changes in the placenta and the actions of special hormones produced in the foetus, the placenta or the pituitary. It must be confessed, however, that we do not know precisely why at the end of about two hundred and eighty days the human uterus is stimulated into expelling its contents. Once parturition has been completed the puerperium begins. During this period the reproductive organs slowly return to a resting condition, whilst the breasts become active. The involution of the uterus (its return to normal) takes about eight weeks.

The Breast and Lactation

The breast is a gland made up of many small lobes, the ducts of which converge upon a central point, the nipple. The nipple contains erectile tissue which, on stimulation, becomes turgid and thus facilitates suction by the child. During pregnancy there is a marked development of the mammary glands and two or three days after parturition they begin to secrete milk. Prior to this there appears at the nipple a small amount of opalescent fluid called colostrum. Once the secretion of the real milk begins, its supply is maintained by the regular emptying of the ducts. If emptying of the breasts is discon-

tinued secretion stops and involution occurs. It is believed by many physiologists that the rapid development of the breasts during pregnancy is the result of the action of a hormone produced first in the ovary, then in the placenta and finally in the developing foetus. The amount of milk increases during the first six or seven months, and then diminishes. Lactation generally lasts from seven to nine months. In spite of the fact that the activity of the breast is under the control of hormones, the secretion of milk may be adversely affected by an emotional upset. It is probable that this effect of the emotions is exercised through the pituitary. Certain drugs are known to be excreted in the milk, and care must always be exercised by the physician in prescribing medicines to a nursing mother. Some drugs (for example, pilocarpine) are believed to increase the flow of milk and others (belladonna and atropine) to diminish it.

Fertility

Childlessness is a common condition in civilised communities, and there are some reasons for believing that it is one which is becoming commoner. According to the census of 1911, 16.6 per cent of married couples in England and Wales were childless. Contraceptive practices are responsible for a part of this fall in the birth rate, but they are less responsible than many of the opponents of birth control would have us believe. Most married couples who avail themselves of birth control use it in order to postpone, or to space, pregnancies, rather than to prevent conception altogether. When childlessness is involuntary it may be due either to complete sterility of one of the partners, or to lowered fertility on the part of both. The latter is the commoner explanation. In the male complete sterility is usually due to an absence of spermatozoa in the semen. They may be absent because they are not being formed in the testes, or because there is a

blockage in the complicated passages along which they have to pass. In the female sterility is sometimes explained by similar causes; that is, by a failure in ovulation, or by an occlusion of the Fallopian tubes. Medical men are now able to diagnose the existence of a blockage in the tubes. If air be blown into the uterus it escapes through the open ends of the Fallopian tubes into the abdominal cavity, and because of this escape the pressure of the air within the uterine cavity, as measured by a manometer, does not increase. Should, however, the tubes be blocked no air will escape and the pressure registered by the manometer will rise. Sometimes this method of examination by opening up the tubes has a curative value.

Lowered states of fertility in both sexes are often the result of a fault in the endocrine system, such as a deficiency of the testes, ovaries or of the pituitary gland. Sometimes such defects can be remedied by appropriate treatment; sometimes they must be regarded as incurable. It will be recalled also that infertility may be caused by a lack of vitamin E, a condition which is easily remedied by the taking of wheat-germ oil. Balzac once said that the divinity that presided over maternity was Chance, and his remark was fully justified. So many favourable conditions must exist if the spermatozoon is to succeed in reaching, and in uniting with, the ovum that success in treating infertility can only result from attention to a great many details.

CHAPTER XII

PHYSIOLOGICAL DIVERSION

THIS examination of man from the point of view of physiology has now been completed. All that remains to be done is to deal with certain side issues which arise out of our consideration of the working of the human body. It will be realised that physiological knowledge has been derived mainly from four types of observation: the study of the structure of the body, the chemical analysis of its fluids and secretions, the noting of the changes resulting from damage or disease, and experiments performed on animals. It is no exaggeration to state that the rapid advances made by physiology during the last hundred years have to a very large extent been due to information gained from animal experiments. Not only has physiology to acknowledge its indebtedness to this method of investigation, but also modern medicine. Medicine, being based on physiology, is equally dependent on this form of experiment. That this is an incontestable fact will not be doubted by anyone who has read this book. Any statement that modern medicine could exist if animal experiments were abolished is entirely false. Should such experiments be forbidden, not only would all further progress be prevented but many of our most valuable methods of treatment and diagnosis would have to be abandoned.

Unfortunately the anti-vivisectionists in their ardour for their cause have been guilty of gross misstatements on this subject. They have even asserted that animal experiments in addition to being unnecessary are, generally speaking, misleading. By means of such propaganda £750,000 have been

abstracted from the pocket of the charitably-minded public for the cause of obstructing the efforts of the pioneers of physiology and medicine. Actually there is only one valid argument that can be brought against the use of animals for experiment, the ethical argument used by G. Bernard Shaw. This ardent opponent of this form of medical research asserts that, even although knowledge has been gained by such means, the gain is at a cost which is unjustifiable. Spiritually, man cannot afford to gain knowledge by inflicting suffering. If anyone truly holds this belief his opinion is entitled to respect, and logically he has placed himself in an unassailable position. But should such a belief become that of the majority, instead of, as at present, that of a minority, we in our turn must make payment. We must be prepared not only to handicap grievously the future progress of science, but also to give up the means by which we are at present able to conquer disease. Moreover, if any new method of treatment be found, such as has recently been found in the drug prontosil, it will have to be tried out on human beings with all the risks that this entails. And even the animals themselves will have to make payment. Between April 1929 and March 1930 over two millions of cattle were inoculated against rinderpest, haemorrhagic septicaemia and blackwater, with a reduction of the mortality amongst the inoculated to one-thirty-sixth part of that which existed amongst the uninoculated. Under the new conditions these animals will all have to face the prolonged suffering that death from these cattle diseases entails.

There is a certain element of justice appertaining to the fact that the rat, which causes so much material loss to man and which is an agent in spreading disease (*e.g.* bubonic plague), is the animal to which medicine owes so much in its struggle with disease. To the bacteriologist, to the chemist and to the vitamin researcher the rat has proved invaluable.

More than one pioneer has dedicated his published work to the most important of his laboratory collaborators, the rat.

One common misapprehension must be dispelled while commenting on this vexed subject of vivisection. Many people believe that vivisection, in common with inoculation, is widely practised in laboratories and medical schools. This is not the case. In order to obtain a licence for vivisection a research worker must first obtain the signatures of two eminent medical men in high official positions, as well as that of the Home Secretary. He must state beforehand the exact nature of the experiments he intends to perform and the knowledge which he hopes to obtain from them. He must carry out his work in a recognised laboratory where he is visited and his work inspected by Home Office officials. He must undertake to destroy any animal that appears to be suffering unnecessary pain, and must forward a complete account of his work when he has concluded it to the Home Office.

The study of physiology as an isolated subject is apt to give the student a lop-sided view of man. In the preceding pages he appears before us as an isolated field of physico-chemical reactions, or as a complicated piece of machinery which takes in potential energy in the form of food and changes it into work performed and waste products discharged. If we look at man from the point of view of physiology only, it is inevitable that we should arrive at these conclusions. From the data we have studied this conception of man is justified, but it must be remembered that the data have been carefully selected. Every specialist looks at man from his own particular angle; the chemist from the angle of chemistry, the physiologist from the angle of functions; the economist studies him in terms of economics, and the religious man in terms of spiritual values. Only when we examine all the answers different specialists provide will it be

possible for us to arrive at any conclusions as to what man really is. In the meantime it is sufficient to say that physiologists have abandoned efforts to explain life along purely physico-chemical lines. We have been examining in the preceding chapters a number of physico-chemical processes, but these are but the external expression of an inexplicable phenomenon, life.

To many people it may come as a surprise that knowledge gained in one department of science may be applicable to another department which, at first sight, seems to have but little connection with it. For example, the study of plants would seem to have only a distant relationship to the study of man. The fact that an infusion of the leaves of the foxglove has a powerful influence on the working of the human heart would appear to be purely accidental. Such is not the case. Science is laying more and more emphasis on the oneness of life and on the interdependence of all living creatures. Life on the surface of the planet must be looked upon as a whole and not as an accidental collection of isolated living individuals. By means of very delicate instruments Sir J. C. Bose detected quiverings and shudderings in injured plants. He declared that they were subject to shock and that they often reacted to drugs in the same way as human beings. In the chapter dealing with vitamins we saw that, under the action of sunlight, the skin is able to fabricate the same vitamin D that is found in cod-liver oil. Similarly, embryo chicks possess the ability to synthesise vitamin C, the vitamin of oranges and lemons. Oestrogen, the mother substance of oestrin, the internal secretion of the ovaries, is found in plants, and human oestrin can cause daffodils to flower all the year round. Life is essentially the same, whether it be the life of a flower or the life of a dictator. We need no longer be surprised that medicine for the sick can be found in the leaves of a plant.

The biblical saying that we are fearfully and wonderfully

made has been quoted so often that we have become dulled to its truth and beauty, but who can study the anatomy and physiology of the human body without being thrilled with a sense of wonder and awe? Charles Darwin once wrote: 'I remember well the time when the thought of the eye made me cold all over'. The same organ made a profound impression on the philosopher Hume. 'Anatomise the eye: survey its structure and contrivance; and tell me, from your own feeling, if the idea of a contriver does not immediately flow in upon you with a force like that of a sensation' (*Dialogues concerning Natural Religion*). Teleogical forms of thought are eschewed by all scientists, but it is impossible to study science without being filled with a sense of plan. Life on this planet cannot be an accident, the result of the interplay of blind forces. Somewhere there exists a plan, even although the limitations of the human mind make it impossible to grasp it. Life on the earth serves some great purpose and consciousness fits into some scheme. This is an idea which endows our existence with a certain dignity, but at the same time may fill us with a feeling of dissatisfaction. Watching our thoughts we become aware of the poverty of our minds compared with the richness of our bodies. All these wonderful contrivances within us, these delicately poised chemical reactions, these carefully adjusted mechanisms, these organs of astounding ingenuity are necessary that we may live—but what of the mind that inhabits this genius which is our body? Are its movements as sure and its activities as purposeful? What aim does it keep before it and what purpose does it serve?

Pelican Books

★

THE PSYCHOLOGY OF SEX

OSWALD SCHWARTZ

Dr Schwartz has produced a companion volume to Mr Kenneth Walker's *The Physiology of Sex* (A72). That book explained for the layman the physical factors in the sexual make-up of men and women. Its success, both with the public and the experts is likely to be repeated by the present volume, which examines the mental, instinctive and spiritual aspects of the same subject.

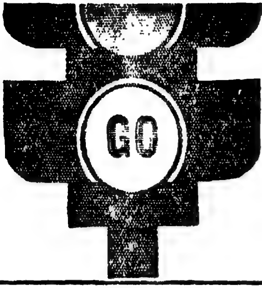
Unlike so many books with similar titles, this is not merely a collection of case-histories illustrating the various forms of sexual aberration. These, indeed, have their place, but the author's main concern is to show the importance of understanding the psychological implications of sex in the normal human being, and to give ordinary people the knowledge to grapple with the problems of personal adjustment in ordinary life.

★

GROW UP AND LIVE

EUSTACE CHESSER

This book has been written to help boys and girls to accommodate themselves to the world in which they are growing up. It deals clearly, coolly and sympathetically with such problems as friendship, sex, the clash between personal and social motives, the need for something more than a material view of life, attitudes to parents and teachers, and plans for the future. It will go far to lessen the bewilderment of young people as they leave behind the acquiescent spirit of childhood and pass, with minds full of enquiry, into the bustling pressure of the grown-up world. The curious mind of the adolescent will be prompted by this wise book to ask the right questions. Parents, teachers and social workers will welcome *Grow Up and Live* for the guidance it offers in finding effective approaches to young minds.



NAVIGATION ON THE ROAD?

When the *Queen Mary* enters a busy port, she and all the other vessels obey the recognized lights and signals on which safe navigation depends.

We, too, obey lights and signals — and rely on them for safety — when we drive or ride or walk on the roads.

We are, in fact, "road navigators." Modern traffic simply could not work without a set of rules which we all accept

Why, then, are there still accidents — far too many?

Partly because we don't all know and understand the rules and principles of Road Navigation. And even if we know them, we forget or ignore them. And partly because some of us don't yet realize that the rules apply to *everyone* — walkers as well as cyclists and drivers. *Any* of us can cause an accident in which we or other people get killed or maimed.

If we all understood the principles of good Road Navigation (based on the Highway Code) and obeyed them *all the time*, traffic would flow faster and more smoothly. We should all get about more easily and, above all, *more safely*. By learning to be skilful Road Navigators, we can help ourselves and everyone else to *get home safe and sound.*

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